AD-A101 363 TRW DEFENSE AND SPACE SYSTEMS GROUP REDONDO BEACH CA F/G 17/2.1
EVALUATION OF DCS III TRANSMISSION ALTERNATIVES, PHASE 1B. FINA--ETC(U)
SEP 80 T M CHU DCA100-79-C-0044
UNCLASSIFIED TRW-35142 SBIE-AD-E100 403 NL

1 OF 3
AD
A101363

AD-E100 403

ADA101363

A101362

(12) LEVEL III

35142

EVALUATION OF DCS III TRANSMISSION ALTERNATIVES PHASE IB FINAL REPORT

30 SEPTEMBER 1980

Prepared for

Defense Communications Agency
Defense Communicaitons Engineering Center
Reston, Virginia 22090

TRW
DEFENSE AND SPACE SYSTEMS GROUP
ONE SPACE PARK . REDONDO BEACH, CALIFORNIA 90278

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER TRW No. 35142	2. GOVT ACCESSION NO. AD-A101 363	3. RECIPIENT'S CATALOG NUMBER AD E100403
4. TITLE (and Subtitle) EVALUATION OF DCS III TRANSMISSION ALTERNATIVES - PHASE 1B FINAL REPORT		5. TYPE OF REPORT & PERIOD COVERED Final Phase 1B Report
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) T. M. Chu		8. CONTRACT OR GRANT NUMBER(s) DCA 100-79-C-0044
9. PERFORMING ORGANIZATION NAME AND ADDRESS TRW, Inc.; Defense and Space Systems Group One Space Park Redondo Beach, CA 90278		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS N/A
11. CONTROLLING OFFICE NAME AND ADDRESS Defense Communications Engineering Center Transmission Engineering Division, R200 1860 Wiehle Ave., Reston, VA 22090		12. REPORT DATE 30 September 1980
		13. NUMBER OF PAGES 243
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office) N/A		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE N/A

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

N/A

18. SUPPLEMENTARY NOTES

N/A

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Defense Communications System
Digital Transmission System
Millimeter Wave LOS System
EHF Satellite System
Airborne Relay Platform
Cable/Optical Fiber System

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This Phase 1B report evaluates system performance for each of the alternative transmission systems proposed in the Phase 1A final report. It also estimates the initial, operating, and maintenance costs of those alternative systems. The alternative systems proposed for each area are compared on a cost-effectiveness basis, the merits of each of the alternative transmission media are then judged from a point of view of practical utility. Furthermore, needed research and development work associated with either alternative transmission media or transmission system alternatives are identified and then recommended.

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

35142

EVALUATION OF DCS III TRANSMISSION ALTERNATIVES PHASE IB FINAL REPORT

30 SEPTEMBER 1980

Prepared by T. M. Chu

Dr. T.M. Chu
Manager
DSC III Project

Approved by N Estersohn

N. Estersohn
Manager
Communications Architecture

Prepared for

Defense Communications Agency
Defense Communicaitons Engineering Center
Reston, Virginia 22090

TRW
DEFENSE AND SPACE SYSTEMS GROUP

ONE SPACE PARK . REDONDO BEACH, CALIFORNIA 90278

BLANK PAGE

FOREWORD AND ACKNOWLEDGEMENT

This Phase IB Final Report is the second of the TRW reports on Evaluation of DCS III Transmission Alternatives. The first report consists of four volumes. These volumes are:

1. Phase 1A Final Report, Evaluation of DCS III Transmission Alternatives
2. Appendix A, Transmission Media
3. Appendix B, Regulatory Barriers
4. Appendix C, Regional Consideration and Characterization.

Project work, as documented in the above noted reports and appendices, has been performed by Defense and Space Systems Group, TRW Inc., and by TRW subcontractors Page Communications Engineers, Inc., Northrop Corporation, for the Defense Communications Engineering Center, Defense Communications Agency, under Contract No. DCA 100-79-C-0044.

This project has been managed by Dr. T. M. Chu and is supported by Messrs. G. J. Bonelle and S. H. Lin, Dr. E. W. Rahneberg; Mr. D. Segel, and Drs J. Soh and C. Y. Yoon, and by other TRW personnel on an as-required basis. Subcontracted work has been managed by Mr. R. A. Pickens and is supported by Messrs. S. T. Black, F. E. Ferrante, and other personnel.

Gratefully acknowledged are the many helpful discussions, suggestions, and guidance offered by Mr. J. R. Mensch of the Defense Communications Engineering Center, throughout the course of this study.

(THIS PAGE INTENTIONALLY LEFT BLANK)

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

TABLE OF CONTENTS (Continued)

LIST OF FIGURES

LIST OF FIGURES (Continued)

LIST OF TABLES

LIST OF TABLES (Continued)

LIST OF TABLES (Continued)

1.0 INTRODUCTION

This is the Final Report of Phase IB effort of the "Evaluation of DCS III Transmission Alternatives" study conducted for the Defense Communications Engineering Center (DCEC), Defense Communications Agency (DCA) in accordance with Contract No. DCA 100-79-C-0044. It was performed by the Defense and Space Systems Group, TRW Inc. and by TRW's subcontractor, Page Communications Engineers, Inc., Northrop Corporation.

1.1 PURPOSE OF PHASE IB EFFORT

The purpose of the Phase IB effort of the DCS III Study is twofold. The first is to evaluate system performance for each of the alternative transmission systems proposed in the Phase IA effort and documented in the Final Phase IA Report. The second is to estimate the initial, operating, and maintenance costs of those alternative systems. Therefore, the alternative systems proposed for each area can be compared on a cost-effectiveness basis, the merits of each of the alternative transmission media can then be judged from a point of view of practical utility. Furthermore, needed research and development work associated with either alternative transmission media or transmission system alternatives can be easily identified and then recommended.

However, it is deemed helpful throughout this Phase IB Report to recognize, in advance, the objectives and scope of the DCS III study. With this background information, the purpose of the Phase IB effort can then be presented and discussed in the right perspective for the readers having not yet read the Phase IA Report (Ref. 1.1-1).

1.1.1 Objective of the DCS III Study

The Defense Communications System (DCS), since its establishment in 1960 has been in a continuous process of growth and evolution. This process is a direct response to the changes of requirements and the advancement of communications technology. The DCS is currently in the transition period from first generation DCS (DCS I) to second generation DCS (DCS II). According to various project plans and schedules, the DCS II component systems will be implemented during the period of FY 80 to FY 85 and will be fully operational by FY 85. The DCS II will consist of AUTOVON, AUTOSEVOCOM, the

integrated AUTODIN System (IAS), the upgraded and digitized terrestrial transmission system, and DSCS II/III. The DCS II will be the basis upon which the DCS III will be designed and implemented.

As a general rule, the life span of communications systems and electronics is about fifteen years. Therefore, by the year 2000, the DCS II existing then needs to be gradually replaced by either new but exactly the same equipment or systems and equipments utilizing new transmission media and/or communications technolgies which are either currently being developed or would be developed from now to the year 2000. This will result in the DCS III.

To provide a basis for the evolving architecture design of the third generation DCS for the years beyond 2000, it is necessary to identify alternative transmission media, communication technologies, system engineering concepts and designs. In addition, international, regional, and national regulatory barriers which may impact alternative media and transmission system designs also need to be identified and documented.

It may be summarized the primary objective of the DCS III study is the intial assessment and projection of transmission media which would be useful for DCS III in the years beyond 2000.

1.1.2 Scope of the DCS III Study

The DCS III study is composed of two phases and seven tasks as listed below:

1. Phase I:

   a. Phase IA:

      Task 1. DCS III Transmission Media Alternatives

      Task 2. Development of Evolving DCS Transmission System Alternatives

      Task 3. Identification of Technology and Regulatory Barriers

   b. Phase IB:

      Task 1. Comparative Evaluation of Alternatives

      Task 2. Relative Cost

2. Phase II:

   Task 1. Overlay of Special User Transmission Requirements

   Task 2. Reevaluation of Alternatives

Phase IA and Phase IB constituted the first year effort of the DCS III study and Phase II constitutes the second year effort. Phase IA has been completed and the results presented in a four-volume report. These four volumes are:

1. Phase IA Report, Evaluation of DCS III Transmission Alternatives
2. Appendix A, Transmission Media
3. Appendix B, Regulatory Barriers
4. Appendix C, Regional Considerations and Characterizations.

This report documents the results of the Phase IB effort.

1.1.3 Objective and Scope of Phase IA Effort

The objective of Task 1 of Phase IA is to identify promising transmission media for the DCS III time frame, to assess or forecast capability, to examine limitations and restraints, and to recommend needed research and development effort to resolve uncertainties in applications.

Brief but broad categorization and examination of all transmission media, either currently in use or under development, were conducted. After preliminary screening, only sixteen media including airborne relay platforms, were deemed worthy of further investigation. These sixteen media were then grouped into four categories as tabulated in Table 1.1-1 and the results of the investigation documented in Appendix A, Transmission Media of the Phase IA Report. A very brief summary emphasizing Phase IA Task 1 material related to the present work is given in Section 2.2.

The objective of Task 2 of Phase IA is to develop two candidate transmission systems employing appropriate transmission media for certain specified areas, satisfying the required capacities and connectivities of each area. Three areas of interest are selected for this purpose. These areas are Oahu Island of the Hawaiian Islands, a portion of the central Federal Republic of Germany, and Turkey.

The alternative transmsission systems proposed for these three specified areas are listed in Table 1.1-2.

Table 1.1-1. Alternative Transmission Media Investigated

I. Guided Waves

1. Coaxial Cable*
2. Millimeter Waveguide
3. Beam Waveguide
4. Optical Fibers*
5. Submarine Cables

II. Radio Waves

1. Terrestrial Microwave Line-of-Sight Transmission
2. Tropospheric Scatter Communication
3. Millimeter Waves*
4. EHF Satellite*
5. Packet Radio*
6. Meteor-Burst Communications System
7. Radio Frequency Spectrum

III. Airborne Relay Platform**

1. Manned and Unmanned Aircraft*
2. Tethered Balloon*
3. High Altitude Powered Platform

IV. Others

1. Alternatives to Electromagnetic Communication Links

Note: * Media have been used for alternative transmission system design.

** Strictly speaking, airborne relay platforms are not transmission media but can be used to extend line-of-sight ranges. Investigation of such platforms has been specified in the Statement of Work for the DCS III study.

Table 1.1-2. Proposed Alternative Transmission Systems

SPECIFIED AREA	PROPOSED ALTERNATIVE SYSTEMS
Oahu Island, Hawaii	1. Millimeter Wave Relay System 2. Buried Cable System a. Option One - Coaxial Cable b. Option Two - Optical Fiber
Federal Republic of Germany	1. Airborne Communications System a. Option One - Tethered Balloon b. Option Two - Aircraft 2. Buried Cable System a. Option One - Coaxial Cable b. Option Two - Optical Fiber
Turkey	1. EHF Satellite 2. Airborne Relay System

For ready reference, descriptions of these systems are briefly given in Section 2.3. It should be emphasized here that these alternative transmission system designs are an exercise used as a means for judging the real utility of these transmission media.

The objective of Task 3, Identification of Technology and Regulatory Barriers, of Phase IA is self-explanatory. Related international, regional and national regulations, rules, procedures, standards, and recommendations which have impact on transmission system design were collected, organized, and reviewed. A summary and outline of regulatory barriers appear in Section 4 of the Final Phase IA Report, Evaluation of DCS III Transmission Alternatives. Appendix B of the Phase IA Report provided detailed documentation to substantiate and supplement this summary and outline. Additionally, a highly condensed summary is given in Section 2.1 of this volume.

Technology barriers include current and forecasted hardware capabilities, propagational constraints such as fading and multiple path, bandwidth limitation, interference, etc. Technology barriers were investigated on the medium basis of the medium investigated and were documented for each transmission medium.

In addition, general topographic and climatic conditions which affect transmission system design were collected for each of the three areas and documented in Appendix C of the Phase IA Report, Regional Considerations and Characterization. Section 2.1 of the report summarized the highlights of Appendix C.

1.2 SCOPE OF PHASE IB EFFORT

As stated previously, there are two tasks for Phase IB, namely:

Task 1. Comparative Evaluation of Alternatives.

Task 2. Relative Cost.

Task 1 evaluates performances of each of the candidate systems developed in Phase IA for each area on a comparative basis. The performance meassures used for this analysis are bit error rate and time availability. System performances are assessed for specified stressed conditions with the total throughout reduced due to either physical disruption or electronic warfare.

In Task 2, the life cycle cost of each of the candidate transmission systems listed in Table 1.1-2 was estimated. These costs include the cost of development (if development work is unique to the system), acquisition, operation, maintenance, and support of the system. Coupled with comparative performance evaluation, the most cost-effective candidate for transmission systems for each area is determined.

Based on the results of these two Phase IB tasks, the most promising transmission medium or media of the DCS III time frame were identified by comparing performance and cost. The conclusions drawn through that comparative study are presented and discussed. Required research and development work associated with the media are also provided in this report.

1.3 APPROACH AND METHODOLOGY

The approaches and methodology used for the current study are depicted in Figure 1.3-1. As indicated in that figure, the basis upon which the analytical investigation was conducted was the Phase IA results--documented in the four-volume Phase IA report. However, additional information and data were collected and reviewed during the performing period. This information and data concerned various aspects of transmission media and systems, namely, system parameters, performance measures, evaluation methodology development, and alternative transmission systems specifications and their modification.

The analytic study was conducted in five interrelated areas. The first area, performance parameter selection, began with collection, review, and analysis of system performance measure parameters. Then appropriate parameters were chosen for the current study. The chosen parameters were bit error rate and time availability.

The second area, evaluation methodology development, concerned the methodology utilized to evaluate system performance of various transmission media. This task identified major system parameters which determine system performance. Data related to these parameters was then collected and organized. Finally, the computation methodology or procedure of prediction was derived and formulated.

The third area was one of the major tasks of the Phase IB effort. The methodology developed was applied to the transmission alternatives proposed in the Phase IA report. This is not a straightforward application but an iterative process. Initial resulting system performance found that, in general, the requirements could not be met, hence the system design had to be modified and performance re-evaluated. This inner iterative loop as indicated in Figure 1.3-1 was repeated several times until the final system design requirements were fulfilled.

The fourth area is the alternative system life cost estimation. Life cost includes initial acquisition cost, operation and maintenance cost and development cost if the development is unique to the particular system under consideration. The cost was expressed in terms of constant 1980 dollars; however, the effect of inflation has been factored into the

estimated life cost. Reduction of cost due to progress of technology involved was predicted and included in the cost estimation.

In the process of costing, one or more modifications have been identified for some of the proposed alternative transmission systems. These modifications resulted in more cost-effective systems. Hence, the system design had been changed accordingly and the performance re-evaluated to ensure the required performance had been met. This is the outer iteration loop as shown in Figure 1.3-1.

The fifth area was the conclusions and recommendations drawn from this Phase IB effort, all concerned with the alternative transmission media and system investigation.

1.4 ORGANIZATION OF PHASE IB REPORT

This report is organized into eight sections, of which this is Section 1, Introduction. A summary of each section's content is described in Figure 1.4-1. Section 2, entitled Phase IA Report Summary, summarizes the findings and results of the Phase IA effort of the DCS III study and describes candidate transmission systems, two each for three specified areas. Section 3 defines system performance measures used for the present work and explains why these measures are chosen. Section 4 provides development of performance methodology for evaluating the alternative transmission systems. In Section 5, the methods developed in Section 4 are used to evaluate performance of the alternative systems as described in Section 2. Section 6 presents estimated life cycle costs of all systems studied. Conclusive discussion of various candidate systems and recommended research and dvelopment work are provided in Section 7.

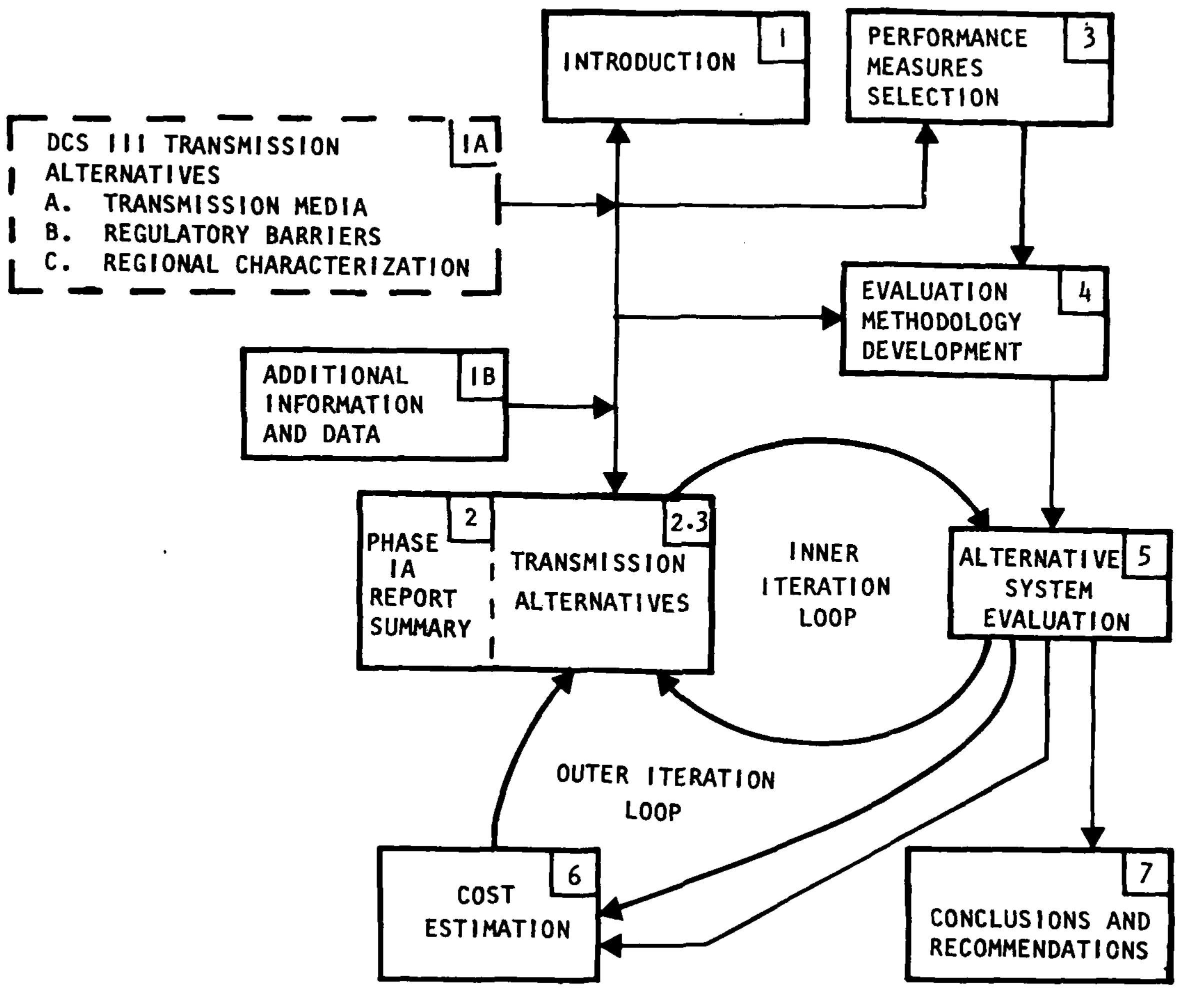


Figure 1.3-1. Approach and Methodology of Phase IB Effort

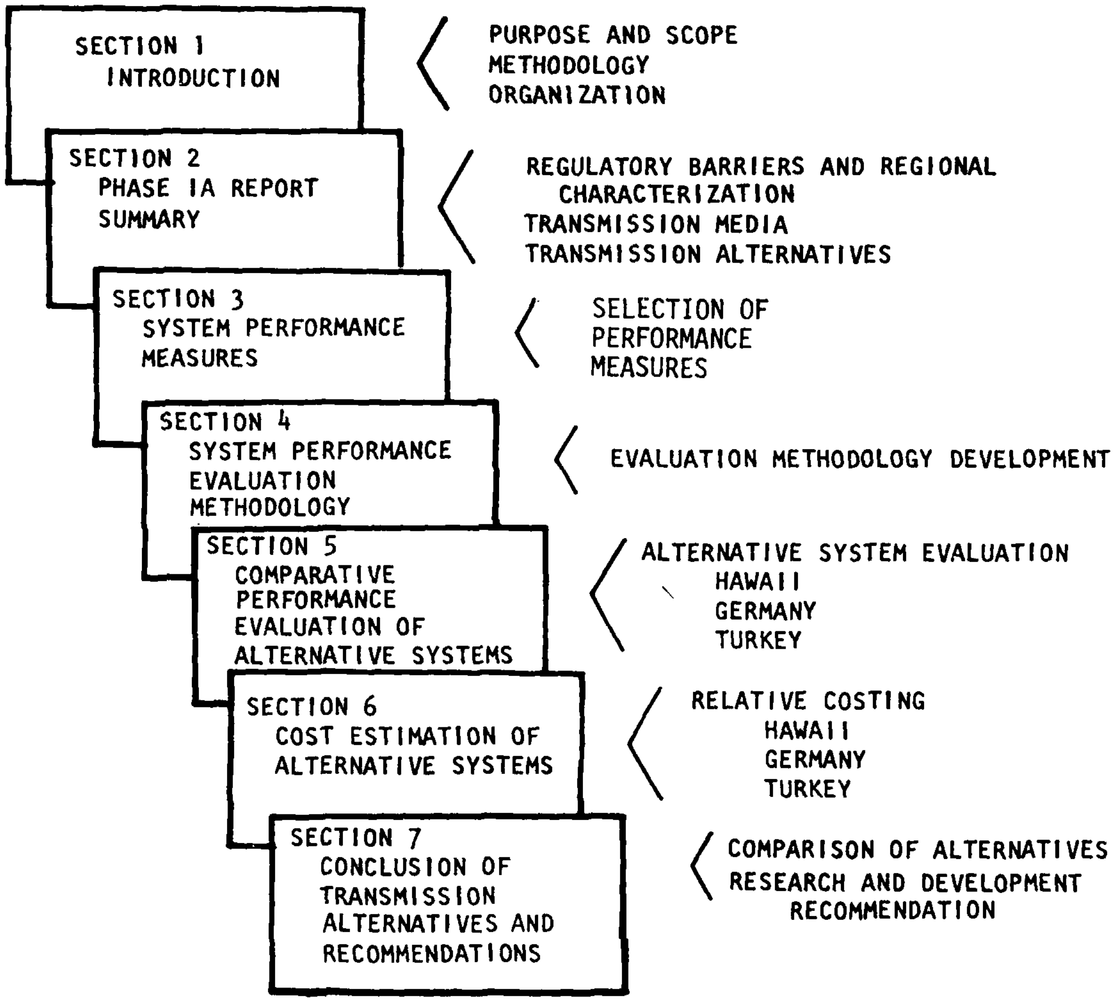


Figure 1.4-1. Organization of Phase IB Report

2.0 PHASE IA REPORT SUMMARY

In the Phase IA effort of the "Evaluation of DCS III Alternatives", three program tasks were completed: DCS transmission media alternatives, development of DCS transmission system alternatives, and identification of technology regulatory barriers. Results of these tasks have been documented in the four-volume Phase 1A Report. For the purpose of ready reference, a very brief summary is given in this section with emphasis placed on those topics which are closely related to the Phase IB work reported in this volume.

2.1 REGULATORY BARRIERS AND REGIONAL CHARACTERIZATION

This section provides a synopsis of international, regional and national regulatory barriers and a summary of topographic and climatic characterizations of the areas of interest. Regulations and environmental factors affect the selection of the transmission media and frequencies to be used and alternative system designs for each area.

2.1.1 International Regulatory Barriers. In principle, any country is free to establish national defense communications as required for the safety of the country. In practice, national defense radio communications is usually subject to regional and international regulations and to some legislation applicable to civil potential mutual interference between various radio spectrum users.

The International Telecommunication Union (ITU) is the agency responsible for adequate worldwide radio frequency management and for compatible operation and interface of communications systems developed and operated by various countries.

The World Administrative Radio Conference (1979 WARC) that concluded in Geneva in December 1979 reorganized existing Radio Regulations and proposed additional Radio Regulations. Radio Regulations (RR) (Ref. 2.1-1) issued by the 1979 WARC become effective on 1 January 1982.

The Plenipotentiary Conference is the supreme organ of the ITU, supported by the Administrative Conference and the Administrative Council, respectively. Permanent organs within the ITU are the General Secretariat,

the International Frequency Registration Board (IFRB), the International Radio Consultative Committee (CCIR), and the International Telegraph and Telephone Consultative Committee (CCITT).

The ITU Radio Regulation offers a means to appraise viability of alternatives to be considered in the DCS III Study as most countries comply with the RR in their frequency assignments. However, the RR does not thoroughly cover alternatives for stations to be installed in all countries. Detailed knowledge of the national regulations of those countries not complying with the RR is necessary. National regulations may limit the use of some bands and impose additional restrictions on the operating characteristics of particular stations.

One rule contained in the RR that may directly impact the DCS III Study is the requirement to notify and register the operating frequency with the IFRB. That requirement, particularly when the station is not operated by a national agency of a country, could result in some administrative and legal problems.

Minimum equipment standards established by the RR probably will not be of importance to the DCS III Study because those standards are well within the state-of-the-art. Also, operational rules established by the RR for some services are not pertinent to the DCS III Study.

2.1.1.1 <u>ITU Radio Frequency Management</u>. The essential duties of the International Frequency Registration Board (IFRB) are:

- To record frequency assignments made by the different countries in order to establish in accordance with the ITU Radio Regulations and with any decisions taken by ITU conferences the date, purpose, and technical characteristics of each assignment, with a view toward ensuring formal international recognition.

- To advise members and associated members in the operation of the maximum practicable number of radio channels and to identify those portions of the spectrum in which harmful interference may occur.

- To perform any additional duties concerned with the assignment and utilization of frequencies prescribed by an ITU conference or by the Administrative Council.

- To maintain essential records.

Any frequency assignment to a fixed, land, broadcast, radionavigation, radiolocation, standard frequency, time-signal, or ground-based meteorological station or to an earth or space station shall be registered by the IFRB in accordance with the following:

- If use of the frequency is capable of causing harmful interference to any other service
- If the frequency is to be used for international radiocommunication
- If it is necessary to obtain international recognition of the frequency use
- If and wherever coordination outside of national borders is required.

Similar frequency registering notices must be accomplished for any new frequency assigned for reception of transmissions from earth or space stations if one or more of the conditions specified above are applicable, and also for any frequency or frequency band that is to be used for reception by a particular radio astronomy station if it is desired that such data be included in the Master Register.

An important rule governing the relative priority of the registration is that a new user of a frequency registered by the IFRB may not use that frequency until a check is made on the possibility of interference with previously registered users.

Regarding evaluation of DCS III Transmission Alternatives, pertinent limitations imposed by the RR relating to frequency-spectrum utilization are as follows:

- Bandwidth limitation
- Bands shared between terrestrial and space communications

A summary of these limitations is provided in Appendix B, Regulatory Barriers of Phase IA Report (Ref. 1.1-1) and the detailed information is documented in Radio Regulation (Ref. 2.1-1).

2.1.1.2 International Radio Consultative Committee. The International Radio Consultative Committee, as one of two technical committees created by the International Telecommunication Union, studies technical and operating factors of radiocommunication and issues and makes recommendations.

CCIR is a technical committee with no regulatory power. Output from CCIR is presented in the form of recommendations, reports, questions, study programs, resolutions, and opinions. Only the recommendations are presented for adoption by CCIR members. CCIR recommendations usually pertain to the following topics:

- System Design Objectives
- Equipment Minimum Performance Objectives
- Interface Characteristics
- Operation and Maintenance
- Transmission Media Modeling

It is important to realize that with the exception of the United States, CCIR recommendations are usually adopted by all international operating agencies. Accordingly, for portions of the DCS III Study pertaining to networks outside the United States or to systems having worldwide projection, CCIR recommendations and reports can be important. The most pertinent matters include limitations imposed on equipment characteristics that may interfere with other systems and, in cases where the DCS system integrates with national systems, interface characteristics and design objectives of the national systems.

Some recommendations and reports of CCIR which have direct impact on DCS III alternative transmission designs are identified and categorized in Appendix B, Regulatory Barriers of Phase IA Report (Ref. 1.1-1). For further detailed information, one has to consult the CCIR XII Plenary Assembly Documents (Ref. 2.1-2).

2.1.1.3 International Telegraph and Telephone Consultative Committee. The International Telegraph and Telephone Consultative Committee (CCITT) is the second technical committee created by the International Telecommunications Union. This committee studies technical, operating, and tariff questions related to communication and issues related to recommendations. The results of CCITT studies are presented in the form of recommendations, reports, questions, study programs, resolutions, and opinions. Only the recommendations are presented for adoption by the CCITT members.

CCITT recommendations cover all technical aspects pertaining to interface of circuits installed and operated by different countries and to compatibility of the end equipments and maintenance specifications, thus ensuring that international lines operate satisfactorily.

Some major CCITT recommendations of the G-, Q-, and V-series have been tabulated in Appendix B, Regulatory Barriers of Phase IA Report (Ref. 1.1-1). Detailed information of these recommendations and other related information can be found in the Orange Books, CCITT VI-th Plenary Assemblies Documents (Ref. 2.1-3).

For radio relay system operating in the UHF and EHF bands, bandwidths and frequency bands, transmission bit rates, signal format, modulation scheme, transmitter power, antenna gain and polarization, receiver noise figure and filter characteristics, etc. are specified. Some essential data impacting system design have been given in various tables in Appendix B, Regulatory Barriers of Phase IA Report (Ref. 1.1-1).

2.1.2 Regional Regulatory Barriers. The one major regional regulatory barrier which may impact on the DCS III alternative transmission system design is the EUROCOM D/I standard.

EUROCOM, formed by the European countries belonging to NATO, is intended to standardize the operational characteristics of equipment manufactured in Europe, thus making such equipment compatible with the military forces of NATO operating under a unified command system. EUROCOM D/I is concerned only with trunk communication systems for combat zones.

The multi-channel trunk links between EUROCOM trunk networks of different nations are known as "gateways".

Multi-channel connections between EUROCOM equipment of one nation and a EUROCOM network of another nation are known as "international access links".

A Hypothetical Reference Circuit (HPR) is defined. Some important system parameters, trunk bit rate, frame structure, synchronization, and multiplexing method are specified with reference to the HPR. Major parameters of gateway station and access link have also been agreed upon.

For radio relay system operating in the UHF and EHF bands, bandwidths and frequency bands, transmission bit rates, signal formats, modulation schemes, transmitter power, antenna gain and polarization, receiver noise figure and filter characteristics, etc., are specified. Some essential data impacting system design have been given in various tables in Section B.2 of Appendix B Regulatory Barriers, Final Phase IA Report of Evaluation of DCS III Transmission Alternatives.

2.1.3 National Regulatory Barriers. This subsection presents a brief summary of pertinent national regulatory barriers of USA, Germany, and Turkey. Detailed regulatory constraints are given in Section B.3 of Appendix B Regulatory Barriers of Final Phase IA Report of Evaluation of DCS III Alternative Transmission.

2.1.3.1 United States. In the United States, centralizing control for non-government stations is vested in the Federal Communication Commission (FCC), which was formed under the Communications Act of 1934. However, control of frequencies for stations belonging to and operated by the United States was conferred upon the President. These functions, once conferred on the President, were transferred to the Assistant Secretary of Commerce for Communications and Information by Executive Order No. 12046 dated 26 March 1978. That order created the National Telecommunications and Information Administration (NTIS) with the Secretary of Commerce for Communications and Information as its administrator. The Interdepartment Radio Advisory Committee (IRAC) was subsequently combined with NTIA. Although NTIA has no control over military frequency assignments, military agencies are members of IRAC and therefore abide by frequency-management rules and procedures established by NTIA. Within NTIA, Office of Federal Systems and Spectrum Management, which holds responsibility for frequency management of government stations. Coordination with governmental departments and agencies, including the military and the FCC, is obtained through IRAC, which reports to the director of Spectrum Plans and Policies.

IRAC consists of three subcommittees, namely, Frequency Assignment Subcommittee (FAS), Spectrum Planning Subcommittee (SPS), Technical Subcommittee (TSC), and International Notification Group (ING). FAS develops procedures for assignment of radio frequencies, and the Aeronautical Assignment Group (AAG) of FAS oversees certain frequency assignments in bands serving aeronautical mobile and aeronautical radio navigation. The Military Assignment Group (MAG) has similar authority over bands of primary concern to military users. The Spectrum Planning Subcommittee (SPS) plans future allotments of the electromagnetic spectrum, taking into account established or anticipated radio services and the apportionment of spectrum space between government and non-government activities. The Technical Subcommittee (TSC) is concerned with technical aspects affecting use of the electromagentic spectrum and with other matters as IRAC may direct. The International Notification Group (ING) prepares responses to the International Telecommunication Union concerning United States frequency assignments and their notification. The three military services are represented in all subcommittees but have no representation on IRAC.

Military-frequency planning, including joint-function frequency allocation, is conducted in a mutual military effort between the Joint Chiefs of Staff (JCS) and the Military Communication and Electronic Board (MCEB). However, final approval of frequency bands, operating modes, and equipment characteristics rests with the MCEB. The DoD, Army, Navy, and Air Fo-ce have their own frequency management structure. Responsibility to prepare technical standards and spectrum-use policies is vested in the Deputy Assistant Secretary of Defense (DASD). The Electromagnetic Compatibility Analysis Center (ECAC) holds responsibility for ensuring compatibility of frequency assignments and advises the JCS, MCEB, and DASD. Because DoD is not a member of IRAC, coordination of policies established by the NTIA is effected by individual representatives of the Army, Navy, and Air Force, the purpose of which may be to gain three votes on the committee. Although the Defense Communication Agency (DCA) performs system engineering for the Defense Communications System

and ensures that DCS can meet long-term point-to-point and switched-network telecommunications requirements, DCA is not a member of IRAC and has not direct representative to influence frequency spectrum policies established by NITA.

Frequency allocation and subsequent restrictions on each frequency band constitute the heart of the regulatory barrier. The basic frequency-allocation plan is produced by the ITU-sponsored World Administrative Radio Conference (WARC). Because this frequency plan is part of the Radio Regulation (RR), the US as a member country of the ITU therefore must comply with the ITU Frequency Plan in preparing its national frequency plan. The national plan for the United States is contained in the NTIA Manual, Chapter 4, Allotments and Plans. Detailed information of frequency application, coordination, and allocation is briefly discussed in Section B.3.1 of Appendix B, Regulatory Barriers as stated in the beginning of Section 2.1.3.

National Technical Standards applicable to DCS III are NTIA Standards and Military Standards. Standards prepared by NTIA are contained in the NTIA Manual, Chapter 5, Technical Standards Requirements and Objectives. These standards define minimum performance requirements (MPR) and design objectives applicable to equipment used by government radio stations. The MPR given in Chapter 5 of the NTIA Manual may be applicable to the DCS III alternative system design and pertinent data on bandwidth calculations, antenna-pattern limitation, power and modulation limitation are reproduced in Section B.3.1.4 of Appendix B, Regulatory Barriers of Final Phase IA Report. If appropriate technical data are not found in the NTIA Manual provisions of the ITU Radio Regulations normally apply. Otherwise, data contained in current recommendations of the CCIR and CCITT are used as a guideline.

Military standards issued by DoD provide technical design standards for military communication systems, and include system-performance objectives for end-to-end circuit quality and availability and equipment performance parameters. Military Communications System Technical

Standards are divided into the three groups consisting of Common Standards (MIL-STD-188-100 series); Tactical Standards (MIL-STD-188-200 series); and Long-Haul Standards (MIL-STD-188-300 series). Standards dealing particularly with transmission-media capabilities and with end-to-end system performance objectives are MIL-STD-188-100 and MIL-STD-188,322, although items concerned with reference circuits, noise, and Bit Error Rate (BER) budgeting are still under consideration and may eventually be modified.

In times of war or national emergency, the President has the right to control all available telecommunication resources of the nation for utilization. Coordination for military use of non-government bands either at test ranges or for tactical and training operations is established between FCC field personnel and military field personnel. Army, Navy and Air Force dockets for the FAS agenda have complete military coordination concurrence by the three military services at the FAS meetings.

U. S. Forces may install and/or operate communication networks in foreign countries under terms of a particular agreement with the host countries or under the conditions established by a regional defense treaty.

2.1.3.2 Federal Republic of Germany. The Federal Republic of Germany as a member of the ITU is subject to constraints imposed by the ITU Radio Frequency Table and by ITU frequency-management procedures and restrictions. Also, similarly to most other countries, Germany follows or is taking the steps to adopt CCIR and CCITT standards and recommendations for their circuits and systems.

In the Federal Republic of Germany, overall authority for telecommunications is vested in the Federal Minister for Posts and Telecommunications (Budesminister fur Postund Fernmeldewesen). This authority is derived

from the 1977 Telecommunication Equipment Law (Fernmeldeanlagengesetz) which also assigned administrative responsibility for telecommunications to the Deutsche Bundespost (DBP).

In the terms of the Status of Armed Forces Agreement (ARFA), U. S. forces stationed in Germany have the authority to establish communication networks in specific bands, particularly in the 7.25 to 8.4 GHz band. As part of NATO, U. S. forces may receive authority through ARFA to establish a communications network, if that network is considered a NATO infrastructure. Otherwise, an authorization for installing or operating a network must comply with rules and regulations of the Bundespost and the Fernmeldetechmisches Zentralant (FTZ).

For new systems in Germany it is advisable to use radio communications operating in frequency bands already allocated to the U. S. forces by the Status of Armed Forces Agreement and through NATO agreements. The installation of cables, wires or poles outside of U. S. compounds may raise strong objections from the Bundespost which would need to be settled by negotiations at a high governmental level.

2.1.3.3 Turkey

Unlike Germany, Turkey has not developed a well-established system for frequency management and for implementation of other regulatory responsibilities. Frequency assignment is under control of the Turkish General Staff (TGS), the General Directorate of PTT is responsible for regulating civil use of telecommunication, and Turkish radio-frequency management is in accordance with ITU Radio Regulations. Turkey follows CCIR and CCITT Recommendations, although implementation of those standards is progressing slowly. For data transmission the PTT adopts CCITT Recommendation 1020.

No particular constraints are expected from the Turkish Regulatory Barriers per se for installation and operation of a U. S. military communications system, provided an agreement supported by the TGS has been reached by the U. S. government. Thus, significant constraints are associated with the political relationship between the United States and Turkey. Although Turkey is a member of NATO, coordination through NATO is not always smooth.

Once an agreement is reached between the United States and Turkish governments, no serious limitations are expected in the selection of communications systems. However, due to a high rate of vandalism in the country, it is not advisable to select a communications system requiring the installation of cables, wires or poles outside secured areas.

2.1.4 Regional Characterization. This subsection summarizes regional characterizations for the three areas of interest. Detailed regional considerations and characterization are documented in Appendix C of Final Phase IA Report of Evaluation of DCS III Transmission Alternatives.

2.1.4.1 Hawaii. Hawaii consists of 124 small islets and 8 major islands which form an archipelago strung out over 2,400 km (1,500 mi.) of the central Pacific Ocean. No other land lies between Hawaii and the United States mainland. The Hawaiian Islands are in a strategic position on shipping routes between the Americas and Japan, China, the Philippines, and other southwest Pacific areas. Hawaii's location has made it a valuable stopping-place for trans-Pacific air routes.

From west to east, the major islands are Niihau, Kauai, Oahu, Molokai, Lanai, Kahoolawe, Maui, and Hawaii. Of these, Oahu is the most important of the Hawaiian Islands.

The Hawaiian Islands may be characterized as having some coasts which are low, sandy, and vulnerable to tidal waves, and some bold cliffs that rise abruptly from the ocean. The sandy beaches lead to low vegetation and flowering trees which quickly give way to rocky, mountainous volcanic peaks.

The maritime climate of Oahu is unusually pleasant for the tropics. The most notable of Oahu's climatic features are the extremely equitable temperature conditions from day-to-day and season-to-season, the persistent trade wind flow from the northeast, the sunniness of the leeward lowlands in contrast to the persistent cloudiness over nearby crests, the remarkable variability of rainfall over short distances, and infrequency of severe storms.

2.1.4.2 Germany. The terrain in the Federal Republic of Germany rises from the coastal lowlands in the north to the Alps along the southern border. The country is generally flat in the north and hilly in the central and western areas, rising in the southwest to more than 1,220 meters (4,000 ft.) above sea level in the Black Forest. Except for the Alpine Region on its southern border, the country does not experience extreme climatic differences. Variations in pressure and temperature are not extreme because the usual differences between a colder north and warmer south are offset by higher land elevation in the south. However, the climate is subject to quick variations when the warm westerly climate of the Gulf Stream collides with the more extreme climate from northeastern Europe.

Surface elevation and relief are the most important determinants in amount of precipitation. The Central Uplands averages a yearly amount of rainfall between 685 and 1,524 millimeters (27 - 60 in.) with the Rhine Rift being near the lower limit. The maximum rainfall for this region occurs in summer, July being the wettest month. Snow may begin falling in October above 460 meters (1,500 ft.) and about a month later at lower elevations. It occurs throughout the country into mid-April and into May at the higher elevations. The least amount of snow occurs in the Rhine area (and along the North Sea coast), which may receive rain instead.

2.1.4.3 Turkey. Except for a relatively small segment along the Syrian Border, which is a continuation of the Arabian Platform, Turkey is part of the great Alpine-Himalayan mountain belt. The intensive folding and uplifting of the mountain belt during the Tertiary Period of geographic history was accompanied by strong volcanic activity and intrusions of igneous rock material, followed by extensive faulting in the Quarternary (most recent) Period. This faulting is still in progress, making Turkey one of the ranking earthquake regions of the world.

The structural complexity is reflected in relief as well as drainage. Wedged between two folded mountain ranges that converge in the east (the Pontic Mountains along the Black Sea and the Taurus Mountains bounding the Mediterranean Sea), the massif of central Turkey is structurally a very complex region composed of uplifted blocks and downfolded troughs covered by recent deposits, that give the appearance of a plateau with rough terrain.

The climate is continental temperate, with some Mediterranean and maritime temperate influences. In the interior plateau, there is a wide range of temperature. Winters are cold with January temperatures averaging -1°C (30°F), and frost may occur more than 100 days during the year. Summers are warm, with high daytime temperatures and cool nights. The mean for July, the warmest month, lies between 20 - 23°C (68 - 73°F). Between 254 and 432 millimeters (10 and 17 in.) of rainfall are received annually on the plateau, the precise amount depending on elevation. May is generally the wettest month, and July and August are the driest months.

Along the coastal regions, winters are mild and summers moderately hot. Along the Black Sea, August is the hottest month with a mean temperature of 22°C (72°F). Along the Aegean Sea, August temperatures often exceed 32°C (90°F). Winters generally contain the wettest months on this coast. The weatern coastal areas do not experience frost, but in the east snow may remain on the ground for as long as four months of the year. Rainfall averages 508 - 762 millimeters (20 - 30 in.) annually along the Aegean and Mediterranean Seas to over 2,540 millimeters (100 in.) along the Black Sea, which is the only region of Turkey with a moisture surplus throughout the year. Along the southern coasts the summers are very hot.

The climate of eastern Turkey is most extreme. Summers are hot and extremely dry; winters are bitterly cold. Spring and autumn are both subject to sudden hot and cold spells.

2.2 TRANSMISSION MEDIA

Various transmission media including those currently being used, tested or developed have been examined for their potential utility for DCS III beyond the year 2000. The detailed results are documented in Appendix I Transmission Media of the Final Phase IA Report. This section presents a very brief summary of these media. The media which have been examined but not used for alternative system design are presented in Subsection 2.2.1, and others used in system designs are discussed in the Subsections 2.2.2 through 2.2.6.

2.2.1 Summarized Media Investigation Results. Various transmission media investigated can be categorized into four broad groups. These groups are guided waves, radio waves, airborne relav platforms, and miscellaneous. A brief summary of each medium not proposed for use in DCS III transmission alternatives is given in this section.

2.2.1.1 Guided Waves. Radio communications can be classified according to the propagation mechanism into two broad categories of guided waves and radio waves. In the case of guided waves, either a metallic or a dielectric guide is present along which the electromagnetic waves propagate. The guided waves investigated include:

- Coaxial cable
- Millimeter waveguide
- Beam waveguide
- Optical fibers
- Submarine cable.

Coaxial cable and optical fibers are the two media types employed for the proposed DCS III transmission alternatives and are discussed in subsections 2.2.2 and 2.2.5, respectively.

1. Millimeter Waveguide

The millimeter waveguide being developed currently in the U.S., Britain, France and some other countries, utilizes a metallic circular tube with a diameter in the range of 50~60 mm. The TE_{01} circular waveguide mode is used for transmissions where the attenuation decreases with

frequency. The frequency band considered is in the range of 30 to 70 GHz with an available bandwidth of a few tens of GHz. The system capacity demonstrated is from 20,000 to 300,000 voice channels. Various forms of phase-shift keying have been employed. Repeater with a gain of about 70 dB at a central frequency of 40 GHz are used with spacing varying from 20 to 60 km. It is a very large capacity system.

Since the diameter of the millimeter waveguide is many times the wavelength, hundreds of higher order modes can propagate simultaneously. This imposes attenuation, modal coupling, and dispersion problems. To minimize the conversion and re-conversion and to suppress the high-order modes, some special measures have to be used to construct the waveguide. Most commonly used measure are straight and precision tubing, dielectric lining, and helix construction. These measures make the millimeter waveguide costly. To keep the deployed guide straight and to use a large band radius further complicates the right-of-way problem and increases the implementation cost.

The basic research, development, and test of millimeter waveguide transmission system have been completed by Bell Laboratory in the 1960's. System testing and further refinement of millimeter wave transmission systems are presently in progress. However, it is apparent that this medium is a very large capacity and a very costly system. It is cost-effective only for a very heavy traffic trunk. Therefore, it may not be suitable for DCS III use in the near future.

2. Beam Waveguide

Beam waveguide is another very large capacity transmission media. Either microwave band or light wave is used for transmission. The electromagnetic energy is confined in a tubular structure with one of the following three mechanisms for guidance: irises, lenses, or reflection mirrors. The ability of a beam waveguide to guide an electromagnetic beam is severely limited by tolerance of the guiding structure; therefore, like the millimeter waveguide, beam waveguide requires absolute straightness, except for intentional bends. Any structure variation in temperature, aging, earth movement, or medium turbulance caused by temperature gradient increases beam attenuation. Experiments have been conducted in both microwave and otpical frequencies, with typical attenuation of one dB/km

or less for light transmission. It is a promising medium for long distance, heavy-traffice trunk needs. However, some technical problems such as long-term stability, automatic control, and alignment of lenses or mirrors and circuits await to be solved. Recent successful and fruitful technology advancements have produced optical fibers of compatible attenuation with less bulk and without stringent physical requirements; however, it does not appear that needed research and development work for beam waveguide are currently conducted with much enthusiasm. It is thus concluded that the application of beam waveguide to DCS III is rather far out and certainly not in the DCS III time frame.

3. Submarine Cables

The submarine cables were extensively used in the 1950's and 1960's to carry transoceanic telephone traffic until INTELSAT Satellite I; however, even for the time being, various submarine cables still carry a sizeable intercontinental traffic.

Submarine cable technology has experienced vast advancement in the last four decades. The most recent advanced submarine cable, TAT-6, was completed in 1976 and connects the USA with Europe. This 6100 km cable, using SG submarine cable, jointly developed by the USA, Britain, and France, with 990 solid state repeaters, 30 block equalizers and 5 shore controlled equalizers, carries 4200 high quality voice channels. A new submarine cable with a bandwidth of 125 MHz, in contrast with the 30 MHz bandwidth SG cable, is being developed now and plans for routes TAT-7 and TAT-8 have been discussed. This is because diversified telecommunications comprised of submarine cables and satellites is justified and mutually beneficial. Note that the 4200 circuit SG cable and the 5320 circuit NG cable in the Mediterranean Sea are compatible with the 6000 voice channel capacity of the current INTELSAT-4 Satellite. However, the planned life-span for a satellite is 5 to 7 years, but for a submarine cable it is 20 years. Acutally, the TAT-1 Atlantic cable at the time of retirement in 1978 was still in operating condition and had been providing satisfactory service for 22 years.

It is anticipated that the use of optical fiber instead of coaxial cable, and the introduction of optic switching and processing will

transfer the current point-by-point submarine cable system to an undersea communication network.

2.2.1.2 Radio Waves. Radio waves media investigated are the following:

- Terrestrial line-of-sight transmission
- Troposphere scatter communications
- Millimeter waves
- EHF satellite
- Packet radio
- Meteor-burst communications system
- Radio frequency spectrum.

Millimeter waves, EHF satellite, and packet radio are discussed in subsections 2.2.3, 2.2.4, and 2.2.6, respectively. The other media are summarized in the following paragraphs.

1. Terrestrial LOS Transmission

Electromagnetic energy can be radiated in narrow antenna beams in UHF and EHF bands and especially in the frequency range of 1 to 10 GHz. Most terrestrial microwave transmission systems use line-of-sight (LOS) propagation between radio relay stations, typically resulting in approximately 30 mile distances between towers. In general, most LOS links presently in use operate between 2 and 8 GHz. The frequency carriers of present microwave LOS systems are mostly frequency modulated (FM) by a large number of voice channels, from 1500 to 3600 channels and up to 6000 channels with single sideband amplitude modulation (SSB-AM). In addition to the analog systems, there are the newer digital radio relay systems in which the carrier is digitally modulated by binary data ranging from 90 to 200 Mbps, with 1300 to 2900 voice channels digitized by pulse code modulation (PCM). Lack of available frequency band and demand for wider bandwidths results in expansion into the higher frequency range.

Some of the advantages of microwave LOS systems are as follows:

- The atmosphere used as the transmission medium has an extremely wide transmission bandwidth
- Low interference because of high antenna directivity

- External noise is negligible
- LOS links are relatively easily implemented and modified
- Geographical barriers are easy to overcome
- Voice channels and video channels can be transmitted by the same equipment

The disadvantages of LOS systems include the following:

- The number of VF channels or video channels that can be transmitted are limited by the available (assigned) frequency spectrum
- Transmission loss due to different types of fading, attenuation by rain, and other anomalous (abnormal) propagation
- Signal degradation due to different types of interference.

In many cases, microwave LOS system perfromance is limited by natural parameters of the transmission medium such as the following:

- Attenuation by rain, snow, hail, clouds, etc.
- Scattering by irregularities in the refractive structure of the atmosphere
- Refraction, ducting, and multipath resulting from atmospheric layers
- Dispersion resulting from frequency-dependent properties of the lower atmosphere
- Reflection, scattering, multipath resulting from irregular terrain and man-made structures.

The above limitations are usually overcome by using directive antenna, space diversity (including height diversity), frequency diversity and polarization diversity. Frequency coordination is required for the systems operating in frequency bands which are shared with satellite communications systems.

2. Tropospheric Scatter Communication

The non-homogeneous structure of the troposphere is capable of scattering high frequency electromagnetic energy. In a troposcatter system, a transmitting antenna and a receiving antenna are spaced at a distance much larger than the line-of-sight range and pointed to a common scattering volume in the troposphere at the mid-point of the great circle path. A troposcatter communications system usually operates with high transmitting power and a large high gain antenna.

However, increasing antenna size beyond a certain limit, diminishes the antenna gain increase by a factor related to the ratio of the scatter angle to the antenna beamwidth called aperture-to-medium coupling loss.

Typical troposcattering communications systems allow transmission up to 120 voice channels in the 100 MHz to 5 GHz fequency range. One tropo span is usually limited to 600 miles (1000 km). Troposcattering systems presently operate in the preferred frequency bands of 100, 400, 450, 750, 800, and 900 MHz and 1.8, 2, 4, and 5 GHz. Typical transmitter powers are from 5 kW to 50 KW, and receiver voice figures range from 2 dB at 900 MHz to 9 dB at 5 GHz. Typical antenna dimensions are 10 to 120 feet maximum. Frequency diversity and/or space diversity are commonly used.

Troposcatter communications have been developed into a highly successful method of radio communications which provides the following advantages not offered by other media:

- High grade multichannel service over 50 to 600 mile distances in a single span
- High propagational reliability on a year-round basis with a properly designed system
- Capability for use in rugged or otherwide inhospitable terrain, or over a stretch of water where other means of communications are impractical or impossible
- Relatively high degree of security compared with other communication methods
- Minimal deliberate or unintentional interference unless interfering transmission is within beam and range of other troposcatter systems.

Disadvantages associated with the troposcatter systems are:

- Very large antenna system
- Higher power transmitter required
- Limited bandwidth due to frequency-selective fading cause by multipath propagation
- Limited communications range

Although most existing troposcatter links employ frequency division multiplex and frequency modulation, development of high-rate digital transmission techniques for LOS and satellite communications has led to interest in considering similar techniques for troposcatter links. This interest

is heightened by the need for encryption as well as by the desire to integrate troposcatter systems into larger digital nets. Currently, some research and development for digitizing troposcatter systems are in progress.

3. Meteor-Burst Communications Systems

A meteor-burst communications system (MBCS) is a medium range system operating at VHF (30 - 300 MHz) band that can provide a rapid, secure, two-way digital communications service. Other types of services such as voice and facsimile, although they have been tested, have not yet been implemented. MBCS operation is based on the use of the meteoric forward-scattered wave phenomenon induced by the ionized trails left behind by meteors penetrating the lower ionoshpere. These forward-scattered signals reach a distance far beyond the usual line-of-sight range because of the high altitude of these trails (80 -11 km). A meteor scattered signal, in general, is much stronger than an ionospheric and/or tropospheric scattered signal. A MBCS, consequently, is a lower-power, and a lower-transmitting rate system in contrast with the scatter system.

Initial investigation of the feasibility of using meteor-scattered waves for communications, design and development, system evaluation, and testing was conducted in the USA and Canada in the years immediately after World War II, and this pioneer work was declassified in 1957. The well-known Canadian JANET system was developed in this period and put into use in 1954. Transmitters at both ends of a JANET system transmit carrier continuously on different frequencies spaced typically one MHz apart with the frequency band of 30 to 50 MHz. When the received signal-to-noise ratio has risen to a pre-determined value due to a formed meteor trail, the stored message is then transmitted until the signal-to-noise ratio falls below the level. The JANET system used separate arrays of four 5-element Yagi antennas for transmitting and receiving. The transmitter power was 500 Watts. The average information rate was 34 words per minute and the individual hourly means of the rate varied widely. The average character error rate was less than 0.1 percent.

Recently the Supreme Headquarters Allied Powers in Europe (SHAPE) Technical Center (STC) has developed a meteor-burst system called Communi-

cations by Meteor Trails (COMET), which incorporates both diversity reception and automatic request for repeat features. The COMET system is designed to provide two-way TTY and data transmission between two ground stations at a maximum spacing of 2000 km. The information is transmitted in frequency shift keying (FSK), with a total frequency deviation of 6 kHz at a signalling rate of 2000 band. The receiving terminal uses a combination of frequency, space, and/or height diversity. The COMET system has been intensively tested over a 1000 km path for several years. Transmitter power was 500 Watts, and the frequencies used were 56 and 39 MHz, one for each direction. The hourly average data rate varied from 40 to 240 bands in unfavorable periods to 50 to 680 bands in favorable periods. The error rate was below one in 3000 characters.

The MBCS has some special features, one of which is the survivability in a nuclear environment. The lower data rate and the intermittent transmission make it unsuitable for DCS use except the data rate or bandwidth can be raised by a few orders of magnitude which is highly unlikely.

4. Radio Wave Spectrum

Finally, the whole radio spectrum was examined from the lower ELF end to the higher EHF end to search for any potential frequency band useful for DCS, but missed in the early screening process. Nevertheless, no promising electromagnetic media except as listed in Table 1.1-1 of Section 1 was found worthwhile for investigation.

2.2.1.3 Airborne Relay Platform. A wideband communications need, such as many analog or digital voice channels, high rate data channels, fascimile, etc., can only be fulfilled by using a high radio frequency as transmission medium. This is because of either the bandwidth limitation imposed by the propagation mechanism or the ITU radio frequency regulations. However, radio waves of frequency in the range UHF or beyond propagate along a line-of-sight path, hence the range of communications is severely limited. The spacing between two adjacent microwave relay stations is about 30 miles, depending on the local terrain condition and the height of antenna towers used.

One way to extend the local line-of-sight horizon is to use an airborne relay platform. Various kinds of airborne platforms which have been either proposed, tested, or are in use, include:

- Manned aircraft
- Unmanned aircraft, i.e., remotely piloted vehicle (RPV)
- Tethered balloon
- High altitude powered platform
- Hight altitude powered glider
- High altitude floating balloon
- Rocket or missile
- Cruise missile
- Parachute.

However, by preliminary examination, only the first four kinds of platform are suitable for long haul day-to-day communications needs. Results of investigations are given in Section A.14, Manned and Unmanned Aircraft, Section A.15, Tethered Balloon, and Section 16, High-Altitude Powered Platform Characteristics and Capability, respectively, in Appendix A, Transmission Media of Final Phase IA Report. The following paragraph briefly summarizes the high-altitude powered platform (HAPP).

The proposed HAPP is either a balloon or an aircraft stationed or orbited over a station at an altitude of 20 km (70,000 ft) for a duration on the order of a year. The operating altitude of 20 km was chosen primarily because wind velocities within the continental United States usually are at their minimum at this altitude. Both of these platforms would be free-flying and would receive their power for stationkeeping via a microwave beam directed upward from the ground. Two HAPP baseline designs are tabulated in Table 2.2-1.

Table 2.2-1. HAPP Baseline Airship Design

CHARCTERISTICS	DESIGN A	DESIGN B
Payload (kg)	130	720
Hull Mass (kg)	34	611
Rectenna Mass (kg)	278	525
Car Motor (kg)	134	214
Volume (m^3)	14,000	37,000
Fineness Radio	4	4
Power (kW)	31	46

It is seen that the design A with payload 130 kg would be suitable for high altitude relay need.

The unique feature of the HAPP is the microwave power system which consists of a ground station and a rectenna on the balloon/aircraft. The ground station converts conventional electric power into microwave power that is focused into a narrow beam by the transmitting antenna. The beam is then intercepted by a rectenna (a rectifier/antenna combination on the balloon/aircraft) comprising a large number of small antennas which feed a rectifier circuit that converts power from the microwave beam to DC power.

The HAPP looks very promising for communications application. Because of its higher altitude than these of an aircraft and tethered balloon, a HAPP can be used to provide a larger cover area or high elevation angles of line-of-sight paths for the same covered area. The high elevation angle is of particular interest for higher frequency application because the rain attenuation subject by radio waves is substantially reduced. However, the HAPP is still under development and is not recommended as an airborne relay platform in this study.

2.2.1.4 Miscellaneous Media. Some transmission media other than electromagnetic waves were also examined. They include:

- Gravitational waves
- Subnuclear particle beams.

It was concluded that they cannot provide useful communication support for DCS III. However, the results are documented in Section A.13, Alternatives to Electromagnetic Communication Links, of Appendix A, Transmission Media, of Final Phase 1A Report.

2.2.2 Coaxial Cable. Coaxial cables are used to transmit electromagnetic signals in the TEM propagation mode. The outer and inner conductors are usually copper with dielectric medium in between them. To add on mechanical strengths as well as to provide additional magnetic shielding, lead or steel tapes were applied over the outer conductor. Additional dielectric insulation will be wrapped around the outer conductor. The outer conductor serves as shielding between adjacent transmission channels

due to skin effect of the good conductor, thus reducing the crosstalk and interferences.

While the 9.5 mm (3/8") coaxial cable has been the only standard cable used in the U.S., in European countries the 2.6/9.5 mm cables are used in the high capacity 12 MHz and 60 MHz systems, and the 1.2/4.4 mm cables are used in 1-12 MHz.

Coaxial cable has been extensively employed to carry telephone traffic either locally or over the U.S. continent. As the demand increased and the technology advanced, the Bell L-system grew from the 600-channel vacuum tube L1 to the most advanced 13,200-channel transistorized and microprocessor-controlled L5E.

The broadband signal, either analog or digital, can be transmitted over a coaxial cable. Although economic reasons as well as high channel capacity per cable have favored the analog FDM type signal in the past and even at the present, the significant progress realized in digital techniques and semiconductor integrated circuits render the digital transmission economically feasible. The North American digital hierarchy is based on the 64-kbps PCM digitized voice baseband. The transmission rates for the multiplex levels from one to four are 1.544, 6.312, 44.736 and 274.176 Mbps, respectively, corresponding to 24, 96, 672, and 4032 voice channels.

A summary of the state-of-the-art of the coaxial cable system is given in Table 2.2-2, from which it may be seen that the most advanced analog system is the Bell L5E system covering a bandwidth of 60 MHz with a capacity of 13,200 voice channels. The most advanced digital system is the Japanese NTT PCM-400 Mbps system with a capacity of 57,000 voice channels. Expectation regarding future expansion of the coaxial cable system capability is also noted in Table 2.2-2.

Table 2.2-2. Summary of the State-of-the-Art Coaxial Cable Transmission Systems

Cable Size	1.2/4.4 mm	2.6 mm or 3/8"
Data Rate	140 Mb/s (1) 12 MHz (2)	400 Mb/s (3) 60 MHz 63 MHz (4)
Repeater Spacing	2 Km	1.55 KM 1 Mile
Capacity Voice Channel	1920 2700	57600 10800 13200
Future Capabilities	18 MHz	565 Mb/s - 800 Mb/s 120 MHz
Remarks	(1) Digital Systems in Europe. (2) Analog System in Europe & Japan.	(3) Japanese PCM-400 system. (4) Bell L5E.

2.2.3 Millimeter Waves. The mm wave band between 30 GHz and 300 GHz (and above) has been receiving considerable attention in the last few years. This has produced significant technology advancements. Applications involving line-of-sight (LOS) propagation through the earth's atmosphere are limited to relative short distances due to well-known atmospheric effects. Even with the range limitations for all weather, ever-increasing demand for new spectral space coupled with technology advancements promise to ultimately result in development of mm wave LOS communication systems. Technology is already sufficiently developed for deployment of high performance LOS communications systems operating in the mm wave band. The capability of already available mm wave components is well beyond present requirements so that any deployment promises to satisfy needs well into the future.

Projection of actual use will depend more on need than feasibility. This view is substantiated by the history of a high performance mm wave communication set which was developed in the early 1970's. This is the GRC-173 radio set which, operating near 10 mm in wavelength, was developed by the Air Force during the early part of the 1970's. It is powered by

a 100 milliwatt semiconductor, uses a 6-foot parabola antenna, and the receiver has a 11 dB noise figure. This equipment used bi-phase modulation at data rates up to 250 Mbps and operated as expected. It was never placed in permanent service for lack of a requirement.

Sources of millimeter wave radiation are currently available in one form or another with power capability ranging from milliwatts up to several hundred kilowatts. One kind of mm source is travelling wave tubes (TWT) which are currently under development in the frequency range from 20 to 50 GHz with output power varying from a few watts to a few kilowatts. The current available TWT from Hughes at 30 GHz with a minimum power output of 2 watts and gain 40 dB is powerful enough for MM Wave LOS need. The Gyrotron which is currently being developed in the USA and USSR is a very high powered device capable of delivering a few kilowatts or more power. It is developed for some other purpose than communication. Other low power sources include field effect transistor (FET), impact-avalanche transit time (IMPATT) device, transferred electron device (TED) also called GUNN device (named for the inventor); these devices are currently being developed and tested in various laboratories over the world. TED, FET, and IMPATT devices currently can generate about one watt continuous power. Parallel operation of these devices to raise the power level to ten watts are being tested. These devices can be modulated directly by varying the supply voltage or bias. Modulation at a rate of 300 Mbps has been reported using PIN diodes at 40 to 119 GHz. If advancements continue, 2 Gbps modulation rate should be feasible at frequencies up to 100 GHz.

Similarly, progress is expected for millimeter wave receiver technology. In 1973 transistor amplifiers were available with 3 dB noise figures at frequencies up to about 8 GHz; by 1990 it should be possible to obtain narrow band transistor amplifiers with 3 dB noise figures at 40 GHz. Current "off-the-shelf" Schottky diodes can be used as a mixer with a 6.9 dB single side band noise figure at 50 GHz. Field effect transistors (FET) are tunnel diode amplifier devices commercially available in 1978 have the noise figures of a few dB in 10 to 30 GHz. Reduction of noise figures in high frequencies is expected. There are a number of high performance receiving devices which require cryogenic temperatures.

These may not have much application to LOS communication on the Earth's surface since the antenna temperature is on the order of 300^{0} K, limiting the maximum improvement to a few dB.

The major restriction for millimeter wave application is the atmospheric effects which show up in these ways:

- Wave attenuation
- Scintillation or rapid fading
- Beam refraction which may show up as long-term fading

Wave attenuation can result from energy loss from the main beam due to scatter from rain drops or energy due to absorption caused by molecular resonances of oxygen and/or water vapor in the atmosphere. Scatter due to rain can also show up as a change in polarization which is of primary concern in systems that use each of two orthogonal polarizations to double the channel capacity. Attenuation is also associated with an increase in antenna temperature to as high as the environmental temperature.

Scintillation or rapid fading is caused by multipath interference between waves travelling over slightly different paths. Different paths can be caused by globules of non-homogeneity in the refractive index of the atmosphere which break up a wave and defraction or refract components into slightly different directions.

Beam fraction always exists for horizontal beams due to the transverse gradient in the refractive index of the atmosphere. This is associated with altitude dependence of the refractivity of the atmosphere. The beam could, at times, end up displaced above or below the receiving antenna so that a narrow beam would essentially miss the receiving antenna. The effect would be long-term fading unless an adaptive system is used which corrects for this effect.

The frequency congestion in the band of 1 to 10 GHz and the rapid progress in millimeter wave technology lead to the development and deployment of millimeter wave communications systems. It is anticipated that these systems will be in popular use by the year 1990 and beyond. However, well-planned system design and test programs are needed to further enhance the progress of the state-of-the-art.

2.2.4 EHF Satellite Communications. The demand for satellite communications services is continually increasing and the capacity available within the 500 MHz frequency bands presently used at 6 and 8 GHz will not be sufficient to meet future needs. Therefore, additional spectrum space will be required with future systems and this can be provided by using frequencies above 10 GHz, where larger bandwidths are available.

The design of both satellites and earth stations in the higher frequency bands will not be significantly changed from those at lower frequencies and no major difficulties should arise due to the great amount of technology available concerning millimeter-wave circuitry. The other problem, which has hitherto inhibited the use of EHF communications, the comparatively high attenuation under bad weather conditions, may be overcome by the higher antenna gains achievable and diversity reception. Thus it would appear that as the limited spectrum space and number of available positions in the synchronous equatorial orbit becomes saturated, the advantages of the EHF band will become irresistible. These include:

- Extra (wider) bandwidth - 1 GHz at 20, 30, and 40 GHz
- Higher gain, small antennas
- Jamming threat less effective
- Smaller spacing between satellites in the same orbit is feasible.

Multiple beam antennas (MBAs) with jammer nulling and/or beam steering offer significant improvement in uplink electronic counter-counter measure (ECCM) performance at the higher frequencies since much smaller beamwidths are available for areas such as the European theater without excessive antenna sizes. As an example, an 0.75^{0} beamwidth is available from a 3 ft. antenna aperture at 30 GHz. The same beamwidth at 7.5 GHz would require a 12 ft. antenna which is not very practical for use in space, particularly since several may be required to cover different areas (e.g., Europe, CONUS and the Middle East).

Current MBAs, such as have been designed for DSCS III are inefficient and may not be suitable for use at EHF where they may be even more lossy. However, recent advances in the design of offset feed antennas appear to

be capable of meeting the more stringent requirements of the higher frequency bands.

The anti-jamming (AJ) performance could be increased considerably over that available in the 7-8 GHz frequency bands if full advantage is taken of the total bandwidth available for maximum band spreading, i.e., 1 GHz. This is beyond the capability of current AJ modems of the frequency hopping or direct sequence types but hybrid modems using a combination of frequency hopping and pseudorandom noise direct sequence band spreading appear to offer an economical solution.

Further improvements in AJ performance can be obtained by the use of an on-board processing which will also provide better control of traffic flow and simplify routing without the use of excessive downlink microwave power resulting from broadcasting point-to-point traffic.

A SATCOM transponder system could play a very important role in long-haul communication for DCS. Another advantage of EHF communication systems is that it is less vulnerable to jamming threat and smaller spacing between satellites in the already crowded orbit. The 30 GHz (uplink) and 20 GHz (downlink) bands would provide adequate performance with an availability of better than 99%. Greater availability, say on the order of 99.99% could be obtained using two terminals spaced about 30 miles apart with ideal line-of-sight radio or a fiber optics link. Suitable technology has been demonstrated in the laboratory and a number of development programs are under way to produce space qualified hardware.

2.2.5 Optical Fibers. Use of optical fiber for communications media was proposed in 1966. Although the best existing fiber was characterized by greater than 1000 dB/km attenuation at that time, it was speculated that losses as low as 20 dB/km be available and it was suggested that such fiber would be useful for telecommunication. This anticipated 20 dB/km fiber was realized in 1970, and from then on progress in the field of optical fiber transmission has been both rapid and abundant. Two excellent examples of progress in the field are the reduction of loss in optical fibers and the reliability improvement of the semiconductor injection laser, the transmitter of an optical fiber communication system.

The loss of an optical fiber operating in the wavelength range of 0.8 to 0.9 m has been continuously reduced from 1000 dB/km in 1968, to 100 dB/km in 1969, 20 dB/km in 1970 and 1.6 dB/km in 1976. Because of the near zero dispersion of single-mode, step-index fiber operating in the wavelength range of 1.2 to 1.4 μm, the recent research and development emphasize the fibers, optical sources, and photodetectors operating in this range, optical fibers with losses of 0.47, 016, and 0.2 dB/km have been reported already.

In the same period the reliability of the AℓGaAs injection laser also has been greatly improved, the projected room temperature mean life being in excess of a million hours based on accelerated temperature test. The photodetectors, needed for optical fiber systems, had already been developed, for fiber communications studies were initiated in 1971. Additional development in this area accomplished over the past decade has mostly been concerned with optimization of existing technology for use with the anticipated data format.

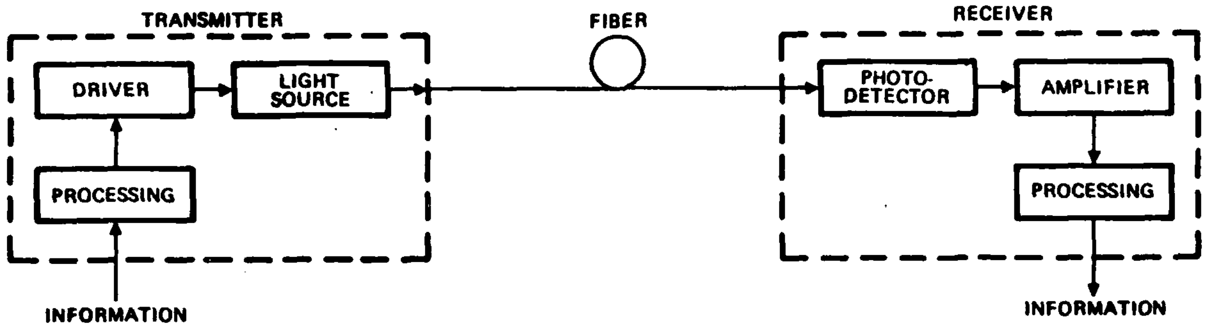
2.2.5.1 Optical Fiber Communications System. Some milestones of optical fiber communications development are tabulated in Table 2.2-3. Due to the rapid component development that has taken place, some optical fiber communication systems have been fielded not only for test but also for actual carrying of commercial traffic. Table 2.2-4 lists a few representative systems.

An optical fiber communication system consists of a transmitter, a receiver, and an optical fiber connecting the transmitter and the receiver. For a long link, one or more repeaters for analog signal or regenerative type repeaters for digital signal are employed.

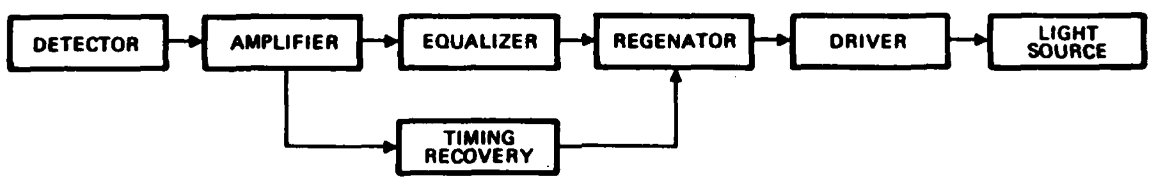
Figure 2.2-1 depicts an optical fiber communications system.

2.2.5.2 Optical Fibers. Various kinds of optical fiber are available. The major ones are:

- Graded-index fiber
- Multi-mode step-index fiber
- Single-mode step-index fiber.



a. Optical Fiber Communication System Without Reapeater



b. Repeater of an Optical Fiber Communication System

Figure 2.2-1. Optical Fiber Communication System

Table 2.2-3. Milestones of Optical Fiber Communications Development

EVENT	TIME
Ruby laser demonstrated, optical communications suggested	1960
Fiber communications proposed	1966
Low loss fiber (20 dB/km) available	1970
Light source reliability (10^6 hr) improved	1977
Photodetector for long wavelength developing	Present
Commercial field test system	1977 - Present

Table 2.2-4. Representative Test and Operational Optical Fiber Systems

NATION	DATA RATE (Mbps)	TOTAL LENGTH/ REPEATER SPACING (km)	DATE (Month/Year)	LOCATION
USA	1.544	9/3.7	April 1977	Long Beach, California
USA	44.7	2.8/2.8	June 1979	Phoenix, Arizona
Canada	6.3	6/1.5	Oct. 1977	Montreal, Canada
Canada	274	52/3.5	Nov. 1979	Alberta, Canada
Japan	32	18/18	Sept. 1978	Tokyo, Japan
Japan	800	7.3/3.2	April 1979	Tokyo, Japan (1.3 μm)
England	8	13/13	Dec. 1976	Suffolk, England
England	140	13/6	Dec. 1976	Suffolk, England
Italy	140	9/9	Sept. 1977	Turin, Italy

Each of these three major types of optical fiber has a core and a region of lower refractive index cladding the core. Depending on how the refractive index varies within the core, the fiber is described as either step-index type or graded-index type. A fiber can support many different guided modes of propagation. Each mode has its own phase velocity and its own field distribution on a cross-section plane.

The most important fiber characteristics are attenuation and dispersion. The major mechanisms which contribute attenuation for waves propagation along the fiber are absorption losses, scattering losses, and radiation losses. The absorption losses in a fiber can be grouped into three categories, intrinsic absorption, extrinsic absorption, and atomic defect absorption. Intrinsic absorption is the power of transmitted light lost in the fiber material as heat. Extrinsic absorption is caused by some impure material in a fiber such as metal ions and hydroxyl (OH). This absorption has been greatly reduced by processing control of the basic material of optical fiber. Further improvement is expected. Scattering losses are causes by density and refractive index variations within the fiber material; these variations are due to frozen-in thermal fluctuations of constituent atoms. The intrinsic scattering losses set the fundamental attenuation limit in fibers. The scattering losses follow the Rayleigh law - inversely prorated to fourth power of wavelength - therefore fiber optics research and development effort has been shifted from the 0.7 to 0.9 μm to 1.2 to 1.5 μm. Radiation is another loss usually associated with fibers caused by microbend. Bend-inducted radiation loss can be significantly reduced by using bends with large radius of curvature.

Communication transmission capacity of a fiber depends on fiber dispersion characteristics. Dispersion effect, shown by broadening in the light pulses propagating along a fiber, limits either the bandwidth of transmission or the spacing of repeaters. There are three major components of dispersion; namely, waveguide dispersion, modal dispersion, and material dispersion. The fiber material is dispersive if its refractive index does not vary linearly with wavelength. This implies, physically, that the phase velocity of a plane wave propagating in such material varies nonlinearly with frequency and, consequently, a light

pulse will broaden as it propagates. Pure silica and several doped silica fibers exhibit zero material dispersion near the wavelength of 1.3 μm. The other important dispersion, particularly for single-mode step-index fiber is the waveguide dispersion which is due to the phase constant of propagation and is not linear with wavelength; then the group velocity varies with wavelength. This kind of fiber waveguide is dispersive and broadens a transmitter pulse. However, at a wavelength of about 1.3 μm the material dispersion exactly cancels the waveguide dispersion. At this wavelength, the bandwidth of a single-mode fiber is enormous (100 GHz/km). It is fortuitous that the minimum attenuation also occurs in this spectral region. The third kind of dispersion, called modal dispersion, only occurs in a multimode fiber along which different modes propagate with different group velocity. The modal dispersion can be dramatically reduced and, hence, the bandwidth improved by grading the fiber index in a parabolic fashion which tends to equalize the group velocities differences.

2.2.5.3 Optical Sources. The sources used for fiber optical communication systems are light emitting diode (LED) and solid state laser diode (LD). These sources should be capable of stable, continuous (CW) operation for long times and of size and configuration compatible with the optical fiber. The power output of these sources is not the most important consideration, however, these sources must be capable of coupling at least microwatts, and preferably a milliwatt or more optical power into a transmission fiber.

In general, LDs offer the advantages, as compared with LEDs, if narrow spectral bandwidth, about 20 Å or less, which is also a very useful characteristic for minimizing the effect of fiber dispersion. Lasers also can be modulated up to a rate of a few hundred megahertz and can be coupled to a fiber because of relatively directional emission. Lasers are now considered primarily for use in single-mode fiber systems. In contrast, incoherent LEDs offer inherent advantages of simplicity of construction and operation, and thus the expectation of long trouble-free operational life. From previous discussions on fiber attenuation and dispersion, it is seen that the wideband incoherent sources must operate at 1.2 to 1.4 μm wavelength where both fiber attenuation and dispersion are low.

Both surface-emitting diodes and end-emitting diodes can provide several milliwatts of power output in the 0.8 to 0.9 μm range, when operated at drive currents of 100 to 200 mA. The spectral width of the output of an LED operating at room temperature in the 0.8 to 0.9 μm range is usually 250 to 400 A at 3 dB points and 500 to 100 Å for material with smaller energy gap operating in the 1.1 to 1.3 μm wavelength region. This broad radiation spectrum limits the bandwidth.

An LED becomes a laser at high current densities by adding a cavity to provide feedback. The optical feedback in a laser diode can be obtained by clearing the parallel facets to form the mirrors of the Fabry-Perot cavity. Many different laser diode structures have been fabricated and tested. The double heterojunction (DH) laser diode is the most widely used continuous wave source for optical communications. A stripe geometry is commonly used for DH injection lasers. For a laser operating in the fundamental transverse mode, the beam width in the plane of the junction is typically 5° to 10° and varies only slightly with diode topology and internal geometry. At least one-half of the power emitted can be coupled into a fiber with a core diameter of tens of microms. Most narrow-stripe laser diodes operate with several longitudinal modes and therefore emit over a 10 to 30 Å spectral width.

The output of a LED can be modulated by varying the driving current. The output is linear with the current over a very wide range from a few to hundreds mA. The modulation bandwidth is limited by the carrier combination time, which can be reduced either by decreasing the thickness of the active lasing layer at low doping level or by increasing the active layer doping level. For surface emitting diode, increasing bandwidth is commonly achieved by heavy doping and/or high carrier confinement. However, both methods decrease the diode efficiency. Hence, the power-bandwidth product of DH lasers with doping level greater than 10^{18} per cm is almost constant. Semiconductor lasers can be directly modulated by varying the drive current. Because the laser output is proportional to the drive current over a broad current range above the threshold level, both analog and digital modulation can be used. Because of the short recombination lifetime of the carrier, less than 10^{-8} seconds, the modulation bandwidth is expected to be up to

a few gigahertz. Table 2.2-5 compares the two basic optical fiber communications light sources.

2.2.5.4 Photodetectors. At the receiving end of an optical fiber communications system, an optical detector or photodetector is employed to convert optical signals to electronic signals which are subsequently amplified and processed. The fundamental process of a photodetector is to generate an electron-hole pair while a photon hits the depletion layer of the detector. The ratio of carrier pairs generated to the incident photon is usually referred to as quantum efficiency. To have high efficiency, the depletion layer must be sufficiently long. On the other hand, because long carrier draft times limit the speed of operation, hence the modulation bandwidth, a thin depletion layer is preferred. Therefore, there is tradeoff between quantum efficiency and speed of operation.

The two commonly used photodetectors are PIN photodiode and avalanche photodiode. At long wavelengths, where light penetrates more deeply into the depletion, front-illuminated PIN photodiodes with wide depletion layers are preferred. In the wavelength range of 0.8 to 0.9 μm, high quantum efficiency in the order of 80 to 90 percent and response time as short as 1 nsec have been achieved. At wavelengths of 1.0 μm or longer, side-illuminated silicon photodiode is used. The response of germanium photodiodes spans the entire frequency range of interest for fiber optics communications, but the relatively high dark current remains a problem. However, experimental silicon PIN diodes with good efficiency and large bandwidth have been built and are now commercially available.

An avalanche photodiode (APD) provides internal amplification mechanism to increase detector output in order to overcome the thermal noise of the following amplifier. The doping profile is so adjusted to result in a narrow region where very high electric fields exist. Carriers which drift into this region can be accelerated to velocities of sufficient magnitude to generate new electron-hole pairs through the process of collision ionization. The multiplication of carriers is random with average carrier multiplication of tens or hundreds being possible. A comparison of these two photodiodes is given in Table 2.2-6.

Table 2.2-5. Comparison of Light Sources

	LED	LD
Spectral bandwidth	Wide ~ 35 nm	Narrow < 2 nm
Coupling efficiency	Low ~ 100 μW	High ~ 1 mW
Structure	Simple	Complicated
Temperature difference	Weak	Strong
Modulation	Low 50 ~ 200 MHz	High 500 ~ 1000 MHz
Remarks	Short wavelength, commercially available, field tested	Reliability to be established, relaxation oscillation and self-pulsation problems

Table 2.2-6. Comparison of Photodetectors

	PIN	APD
Sensitivity	Low	High
Quantum efficiency	~80%	~90%
Response	Fast-sub ns	Slow ~ ns
Noise	Shot-noise limited	Excess noise (factor 5) due to multiplication
Gain	0 dB	10 ~20 dB, optimal gain for noise and bandwidth
Remarks		Temperature compensation for stabilized gain

2.2.5.5 System Capabilities and Research Trends. The advantages of utilizing fiber optics, as previously discussed, which will drive changeover from cable and microwave relay systems to the fiber optic system, can be summarized as follows:

- Very high bandwidth; billion bit per fiber capacity available at low cost by the late 1980s
- Greater bandwidth/volume; orders of magnitude more bandwidth in one-tenth the space
- Rapidly declining unit costs, in contract to increasing copper cable cost
- Extremely low-loss; a few tenths of a dB per kilometer, with low dispersion, virtually eliminating repeaters
- Freedom from electric interference
- Greater security.

Although fiber optics has been developed to a state where many experimental systems have been fielded over the world, only a few systems actually carry commercial traffic. Further reserach and development efforts are essential.

- Realization of low loss cable, connectors and splices
- Improvement of reliability of optical sources, both in 0.8 to 0.9 and 1 to 1.7 μ m
- Development of efficient sources and photodiodes in the 1.3 to 1.5 μm wavelength region
- Stabilization of laser modes under operational conditions
- Development of high bit rate modulation.

High performance optical fiber prices have dropped by a 10:1 factor over the 1975-1980 span, as production transitioned from laboratories to pilot plants. With increased efficiency of high volume production, price will drop by another order of magnitude by 2000. Regarding solid state light sources, there has been rapid advancement over the last few years in areas such as increased lifetime, power output, linearity, radiation pattern, and efficiency. These improvements will likely continue over the next few decades.

In the interest of the current study, a prediction of fiber optic communications system capability has been made and shown in Table 2.2.7. for the period of the 1990s. Because of the dynamic growth and development of the optical field, reassessing the prediction may be needed at two to three year intervals.

2.2.6 Packet Radio. Packet radio is a technology that extends application of packet switching, as evolved for networks of point-to-point communication landlines, to the domain of radio. This technology offers a highly efficient way of utilizing a multiple-access radio channel with a potentially large number of fixed and mobile subscribers to support communications and to provide distribution of information over a wide geographic area.

During the early 1970s the ALOHA project at the University of Hawaii demonstrated feasibility of using packet broadcasting in a single-hop system. The successful Hawaii network led to development of multihop, multiple-access Packet Radio Network (PRNET) under the sponsorship of the Advanced Research Project Agency (ARPA). Packet transmission technology can also be applied to satellite channels. There are two packet satellite experiment efforts, one is the Atlantic Packet Satellite Experiment and the other is the Wideband Experimental Integrated Switched Network. General discussion on packet radio technology and description of experiments mentioned above are given in Section A.8 Packet Radio of Appendix A Transmission Media of Final Phase 1A Report.

2.2.6.1 Packet Radio Experiment. All users in a packet-radio network are assumed to share a common radio channel, access to which needs to be controlled to minimize conflict or overlapping transmission. A variety of theoretical and experimental studies have been carried out to determine the most effective techniques for showing a multiple access (MA) channel. The most common techniques are classic ALOHA, slotted ALOHA, and carrier sense. The simplest technique is classic ALOHA which was designed for very-low-duty-cycle application without any access-control capability. Each user transmits its own message independently,

Table 2.2-7. Predicted Optical Fiber Communcations System Capabilities

	BIT RATE (Mbps)	REPEATER SPACING (km)	CIRCUIT LENGTH (km)	FIBER	SOURCE	DETECTOR
Large capacity, long haul system	1.2 ~ 1.6	15 ~ 30	2,500 ~ 4,000	Single mode	LD	APD
Medium capacity, short haul system	30 - 400	20 ~ 40	200 ~ 300	Single mode or multimode, graded index	LD or LED	APD
Small capacity, local system	10 - 30	50	10 50	Multimode, step index or graded index	LD or LED	APD or PIN

however, once an overlapping or conflicting packet is recognized the unsuccessful transmission will be randomly rescheduled at a later time. This scheme is normally implemented using a positive acknowledgement and time-out procedure. The throughput of a classical ALOHA system increases with the channel traffic to a maximum value of 0.189 which is known as the capacity of a classic ALOHA and occurs for a value of channel traffic of 0.5. If the channel traffic is increased beyond value of 0.5 the throughput of the channel will decrease due to occurrence of conflicts.

The slotted ALOHA is a time-slotted version of random access. In this process, a central clock establishes a time base for a sequence of slots of the same duration as the packets. A user transmits his packet randomly but synchronizes the start of his transmission with the start of a slot. Therefore, if the packets conflicts they will overlap completely, rather than partially. Conflicting packets will be transmitted by each user by waiting a number of slots which will be chosen by each user randomly and independently. The maximum utilization a slotted ALOHA channel is 36.8 percent which doubles that of a classic ALOHA.

One of the more efficient access-control techniques for a packet radio system is the carrier sense multiple access (CSMA) wherein each user first senses the multiple-access channel or a control channel and then transmits a packet only if the channel is idle. If the channel is determined to be in use, the transmission is rescheduled at a later time according to certain rules adopted by various systems. Various elaborations on the CSMA scheme offer the possibility of achieving 70-90 percent utilization of the channel with low end-to-end transmission delay per packet.

Propagational characteristics of the radio frequency band have a major impact on the packet radio design, rendering it desirable for practical packet radio systems to use frequencies in the upper VHF band, in the UHF band and in the lower portion of SHF band. VHF and UHF bands are already heavily allocated and use of spread-spectrum techniques potentially could allow coexistence of a packet-radio system with existing users of the same

frequency bands. However, this is a relatively new concept from the regulatory point, and significant technical issues would have to be solved to establish feasibility of coexistence.

A packet radio system consists of three primary network elements of terminals, control stations and repeaters. A terminal contains the RF and digital processing circuits. Necessary terminal capabilities include the following functions:

- Packet reception, with ability to check the header and text portion and to route the arriving packet to its destination or local user
- Packet retransmission, when acknowledgements are not received in a certain time out
- Efficient routing control between terminal and the control station.

The control station demodulates the incoming packets, stores and switches the information, and remodulates the packets onto a broadcasting channel. In addition it has capability to implement network protocols including initialization, routing, flow control, directory, and accounting functions, and it also serves as an interface to other networks. All the above functions are performed by an on-board microcomputer.

In the event that some of the terminals are too far away from the control station, radio repeaters are used as relay devices which provide network area coverage by extending the range between terminals and stations. A repeater can operate on a single frequency for transmitting and receiving, switching off its receiver momentarily while it transmits a package. Some packages will be lost when this happens, and as in the case of a collision will have to be retransmitted. However, operating at a single frequency saves the expense of frequency-translation equipment. The repeaters use a single frequency for relaying packages to the control location and a different frequency for relaying packets back to the terminals. If two frequencies are used in this way the repeater antennas pointing towards the central station can be highly directional.

For a highly flexible and/or survivable network each terminal should be within radio range of two or more repeaters, so that this increased network interconnectivity would improve flexibility and survivability. Controlled routing procedures permit use of preferred routes to minimize delay and prevent propagation of duplicate messages. However, in the event of repeater failure automatic alternate routing procedures will be implemented.

In 1973 ARPA initiated a theoretical and experimental packat radio program. The primary objective is to develop a geographically distributed network consisting of an array of packet radios managed by one or more minicomputer-based stations and to experimentally evaluate the performance of those stations. The testbed is located in the San Francisco Bay area and it consisted of about 50 fixed and mobile radios distributed north to south from Grizzly Peak, Berkeley to Eichler, Palo Alto and east to west from Mission Ridge, San Jose to Mountain San Bruno. The initial radio equipment designed was the Experimental Packet Radio (EPR) and a new development completed in 1978 was designated Upgraded Packet Radio (UPR). A selected 20 MHz bandwidth and 140 MHz bandwidth in the 1710-1850 MHz is employed by EPR and UPR respectively. Two transmission rates of 100 and 400 kbps are available for EPR corresponding to spread-spectrum pattern of 128 and 32 chips per bit. The data rate of UPR is approximately the same but higher chips per bit rate is used to enhance electronic counter countermeasure capability.

2.2.6.2 Packet Satellite Experiments. There are two packet satellite experiments. The first one is the Atlantic Packet Satellite Experiment which has been completed recently. The second is the Wideband Experimental Integrated Switched Network of which the experiment plan is currently being developed.

The Atlantic Packet Satellite Experiment was jointly sponsored by the Defense Advanced Research Project Agency, the British Post Office (BPO), and the Norwegian Telecommunications Authority (NTA), with participation of

the Defense Communications Agency (DCA) and the USAF Space and Missile System Organization (SAMSO). The satellite network (SATNET) consisted of four INTELSAT standard earth stations located at Efam, WV, and Clarksburg, MS, USA; Goonhilly Downs, England; and Tanum, Sweden. A 38 kHz channel was shared among the earth stations in accordance with demand-assignment multiple-access technique, and this channel is one of the 800 frequency-division multiplexed channels on the global SPADE transponder of the Atlantic INTELSAT IV-A satellite. This full period assigned channel is operated at nominal power levels, supporting 65 kbps data transmission with a bit error probability on the order of 10^{-6} and 10^{-7}. This experiment has been completed and the data is being analyzed.

The other packet satellite experiment is the Wideband Experimental Integrated Switched Network (EISN) which is currently being developed under joint sponsorship of the Defense Communications Agency and the Defense Advanced Research Projects Agency. The network provides a unique experimental capability for investigation of systems issues involved in a communications facility which includes satellite and terrestrial network and which carries large volumes of voice and data traffic. Areas for investigation include the following:

- Demand-assignment strategies for efficient broadcast satellite comminications
- Packet voice communication in a wideband multi-user environment
- Alternate integrated switching techniques for voice and data
- Rate-adaptive communication techniques to comply with varying network conditions
- Routing of voice and data traffic
- Digital voice conferencing
- Internetting between satellite and terrestrial subnetworks.

The planned satellite net includes four earth stations at Defense Communications Engineering Center (DCEC), Reston, VA; ISI, Marina del Rey, CA, Lincoln Laboratory, Lexington, MA; and SRI International, Palo Alto, CA. The DCEC is a site of both a satellite and a terrestrial node as well as of a gateway interconnecting the two. Locations of the other three terrestrial nodes are unspecified.

Among many features of EISN, the following two are of interest to the

DSC III study. The first is the transmission of combined data and digital voice in a wide satellite channel with a variable boundary between these two kinds of traffics. The second is the use of various digital rates of voice transmission; the higher rates are used for periods of less traffic and the lower rates for periods of heavier traffic.

2.2.7 Airborne Relay Platform - Aircraft. Using either manned or unmanned aircraft as an airborne relay platform was considered. Several different kinds of manned and unmanned aircraft were examined. The investigation results are documented in Section A.13, Manned and Unmanned Aircraft, of Appendix A, Transmission Media, of Final Phase 1A Report.

One aircraft which is suitable for airborne relay use with just about right payload, space and power supply, has been identified. The identified aircraft is E-system L-450, which is a multi-mission, single-engine, high-altitude, long-endurance aircraft. This aircraft can be operated as either a manned aircraft or a remotely piloted vehicle (RPV). L-450F is the designation for the RPV version, and the military designation is XQM 93A.

The aircraft can fly slowly in circles at altitude between 13.7 to 16.8 km (45,000 to 55,000 feet) for 24 hours. The L-450 payload capacity is 26 cubic feet. About 20 cubic feet is available as one continuous bay aft of the cockpit, and an additional 6 cubic feet is available in a narrow area off the primary 20 cubic foot payload bay. For L-450F, the RPV version, the cockpit provides another 18 cubit feet for payload. The total payload space is 44 cubic feet, and the total payload capacity is 1100 pounds. Electric power available is 6 kW at 28 Volts.

The L-450 is powered by a PT-6A turboprop engine manufactured by United Aircraft of Canada, Ltd. This engine now has over 10 million flying hours, and it has been installed in 2,000 operational aircraft. The engine experienced an in-flight shutdown rate of 1 per 100,000 hours operating time. The time between overhaul is up to 7,000 hours.

The major parameters given by E-system specification are listed in Table 2.2-8.

Table 2.2-8. L-450 F Specification

DESCRIPTION	SPECIFICATION
Endurance	Over 24 hours
Service ceiling	Over 50,000 feet
Stall speed	61 knots
True airspeed (maximum endurance)	200 knots
Maximum rate of climb	3,000 feet per minute
Time to 40,000 feet minimum	21 minutes
Takeoff distance	1,200 feet
Gross weight (manned)	4,600 pounds
Gross Weight (unmanned)	5,300 pounds
Maximum payload	44 cubic feet
Turboprop engine	PT-6A
Available electric power	6 kW, 26 Volts

2.2.8 Airborne Relay Platform. A tethered balloon can be used as an airborne relay platform. Comparing with aircraft or other relay platforms, the drawback of a tethered balloon is the limited altitude which in turn limits the line-of-sight range. Some technical aspects of tethered balloons have been discussed in Section A.15, Tethered Balloon Characteristics and Capability of Appendix A or Final Phase 1A Report. The following paragraphs provide essential information for the tethered balloon system recommended for use in Germany.

The aerostat consists of the balloon, tether cable, winch, power for wind, and a ground-based mooring structure and controls. Currently, Sheldahl, Advanced Products Division in Northfield, Minnesota, is manufacturing two of the largest state-of-the-art tethered balloons for use as a stable airborne platform. These have nominal volumes of 250,000 cubic feet and 365,000 cubic feet, known as the CBV250A and CBV365A, respectively. The configuration of the mooring and servicing machinery is similar for both sizes.

2.2.8.1 Balloon. The hull and stabilizing fins of these helium-fitted balloons are made of laminates of plastic films and fabric. Their appearance is similar to the commercially deployed blimps used for advertising purposes.

Buoyant forces vary as a function of wind speed and radiation effects on helium temperature. These two parameters can be predicted only within broad limits. For this reason an operational constraint is that the weight of the tether cable should not exceed that which can be safely supported by buoyancy alone in the absence of wind.

High winds and lightning are the principal hazards to survival. Hull, fins and rigging of aerostats have never been damaged while internal pressure was maintained. Failure of the pressure control system, by malfunction or lightning damage, reduces the structural and aerodynamic efficiency to a point where even a moderate wind gust may cause the tether to break.

The CBV 250A, with nominal volume of 250,000 cubic feet, a length of 175 feet, a diameter of 56.8 feet, and a tail span of 82 feet can carry about 4,000 pounds of equipment to 10,000 feet (including on-board power supply and pressure control equipment) and is designed to operate

safely in 70 knot winds at altitude. The CBV 365A is a "stretched" version of the CBV 250A, with an overall length of 220 feet (about that of a Boeing 747) and a load carrying capacity of approximately 8,000 pounds at 10,000 feet or 3,700 pounds at 15,000 feet.

Each aerostat is equipped with an air-inflated fairing to enclose antenna arrays, electronic equipment and other payload components vulnerable to environmental exposure. During flight the aerostat is connected to a ground mooring system by a steel tether cable which incorporates a power cable when power is supplied from the ground.

2.2.8.2 Mooring and Servicing System. The ground-based mooring system consists of a central machinery enclosure and a tower mounted on a large bearing, a horizontal boom which can be rotationally driven, and a circular rail, supporting the boom end. When moored, the nose of the aerostat is secured to the top of the tower.

A single operator can maintain teh aerostat on station and a crew of 4 to 6 persons can launch and recover it. The boom, rail and center bearing permit the system to be rotated either by wind forces on the aerostat and cable or by internal power to minimize aerodynamic loading.

2.2.8.3 Airborne Power Supply. The power supply can be provided by either on-board systems such as a Wankel engine-alternator arrangement or from the ground by means of the tether cable. The power requirements for ground supplied power for either the CBV 250A or CBV 365A are in the same order of magnitude. The CBV 250A requires about 2.5 kilowatts when on station and about 5 kilowatts during retrieval operations, and the CBV 365A requires 2.5 kilowatts on station and about 6 kilowatts during retrieval. The main load is needed for the blowers during the one to two hours retrieval period.

When supplying power from the ground, the 60 Hz supply is converted to 400 Hz and transformed to 3,000 volts for transmission over the tether cable. At the aerostat it is transformed back to standard voltages. The use of 400 Hz reduces substantially the weight of the required transformers.

2.2.8.4 Telemetry and Command System. The telemetry and command system continuously monitors such aerostat data as altitude, windspeed, hull,

fin and windscreen pressure, helium and ambient air temperatures, blower, valve and power system conditions; and vehicle pitch, roll and heading.

The system consists of a control section, housed in a console at the ground control station and an aerostat control unit carried aloft by the aerostat. Figure 2.2-2 shows a powered tethered balloon system.

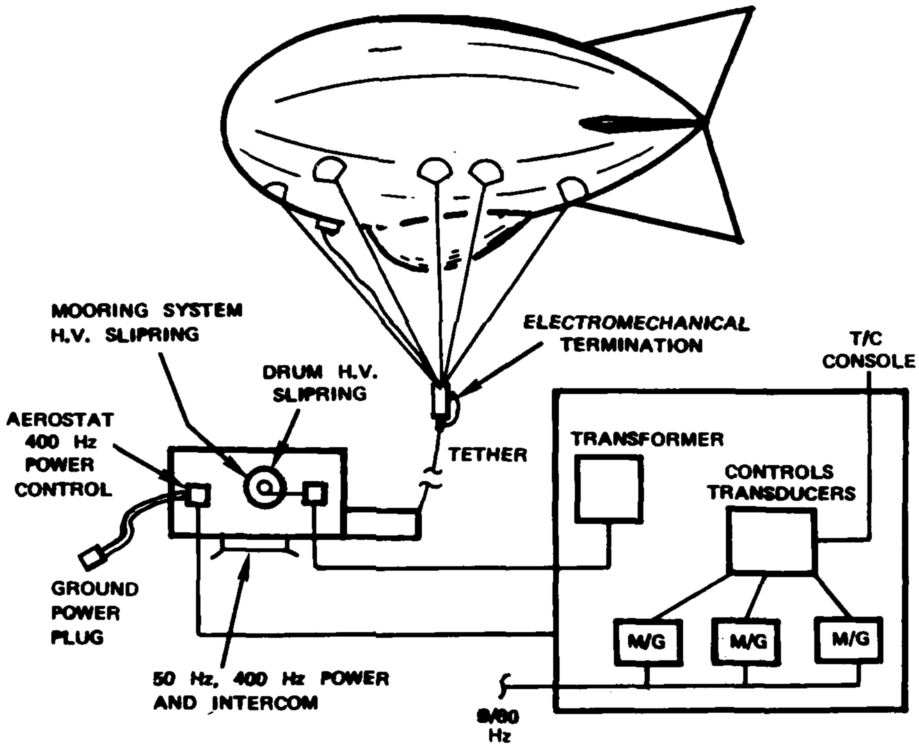


Figure 2.2-2. Tethered Balloon System

2.3 TRANSMISSION ALTERNATIVES

This section presents two alternatives transmission designs for the DCS III time frame and for three areas of interest, namely Oahu Island of Hawaii, Central Region of German Federal Republic, and Turkey. According to the Statement of Work of this project, system design should be conducted for the following type classes:

1. Densely netted DCS user region
2. Sparsely netted DCS user region
3. Regional DCS interconnection.

Central Germany and Turkey are chosen as representative regions for densely netted and sparsely netted DCS user regions, respectively. However, DCEC later instructions were that the regional DCS interconnections be replaced by Oahu Island and that millimeter wave radio should be included as one of the transmission media.

The medium or media for a particular region is selected based on international, regional, and national regulatory barriers, topographic and climatic conditions. Needless to say, the technical constraints of the medium or media are also duly considered.

2.3.1 Hawaii. This subsection presents the baseline system in Hawaii and two proposed alternative transmission designs. However, attention has been placed on the intra-island communications requirements for Oahu Island.

As an initial step in the alternative study, the information about the existing and planned DCS was gathered. However, some essential information was not available. Therefore, the alternative transmission systems designs were made based on given requirements data which includes communication nodes and their locations, and required number of voice channels for each link. A few data links and their data rates were given, hence, these data links were also included in the system design.

Two alternative transmission systems were proposed. These are millimeter wave LOS system and buried cable syste, designated as H-1 and H-2, respectively.

2.3.1.1 Alternative System H-1. A communication network design for Oahu in particular is based both on government supplied traffice requirements between users on Oahu Island and the requirement that both the selected transmission media and network configuration allow 20 to 60% future expandability.

In order to increase survivability of the network, a double star system in Figure 2.3-1 was proposed as a candidate alternative system in the Phase IA effort. Although the double star system has redundancy of equipment compared to the single star system, which deletes double connections, it can be overcome by reducing outages due to intense rainfall or switching station failure. However, in Phase IB effort of performance evaluation and costing, it was found that a mesh type network as shown in Figure 2.3-2 is a better one. The change from two-star geometry to mesh type network is basically caused by line-of-sight paths and related repeater locations selection, which is heavily influenced by terrain features of the island. Furthermore, the access roads leading to these repeater stations were also considered. In addition, the mesh network offers much better reliability by providing redundant routes and switching capability, although switching has not been considered for transmission alternative design as stated previously.

Key factors which influenced the selection of mm-wave bands for short haul communications systems rather than the conventional centimetric bands are:

1. Increasing congestion at the lower frequencies with resultant bandwidth limitation and interference

2. Matured state of mm-wave technology which offers high reliability and compactness.

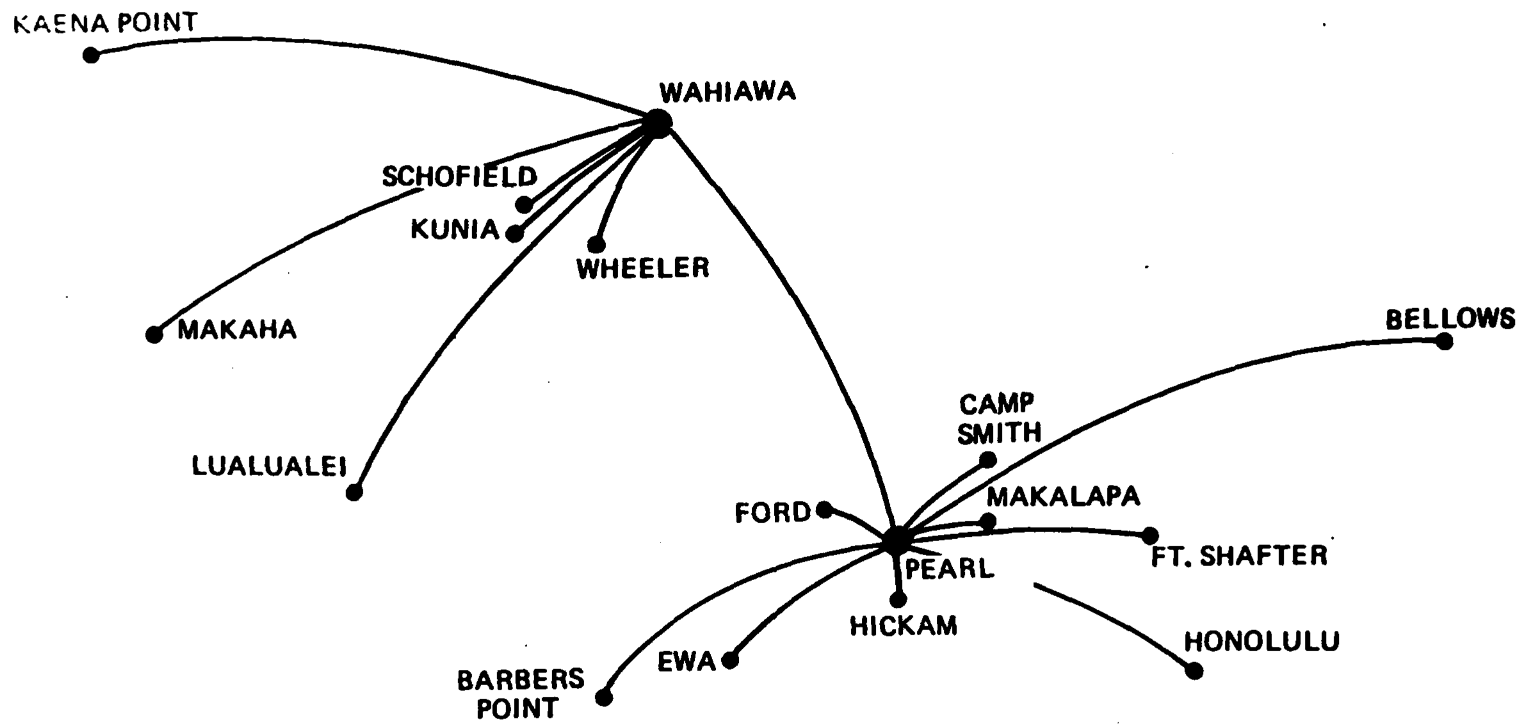


Figure 2.3-1. Candidate Double Star Network for Oahu

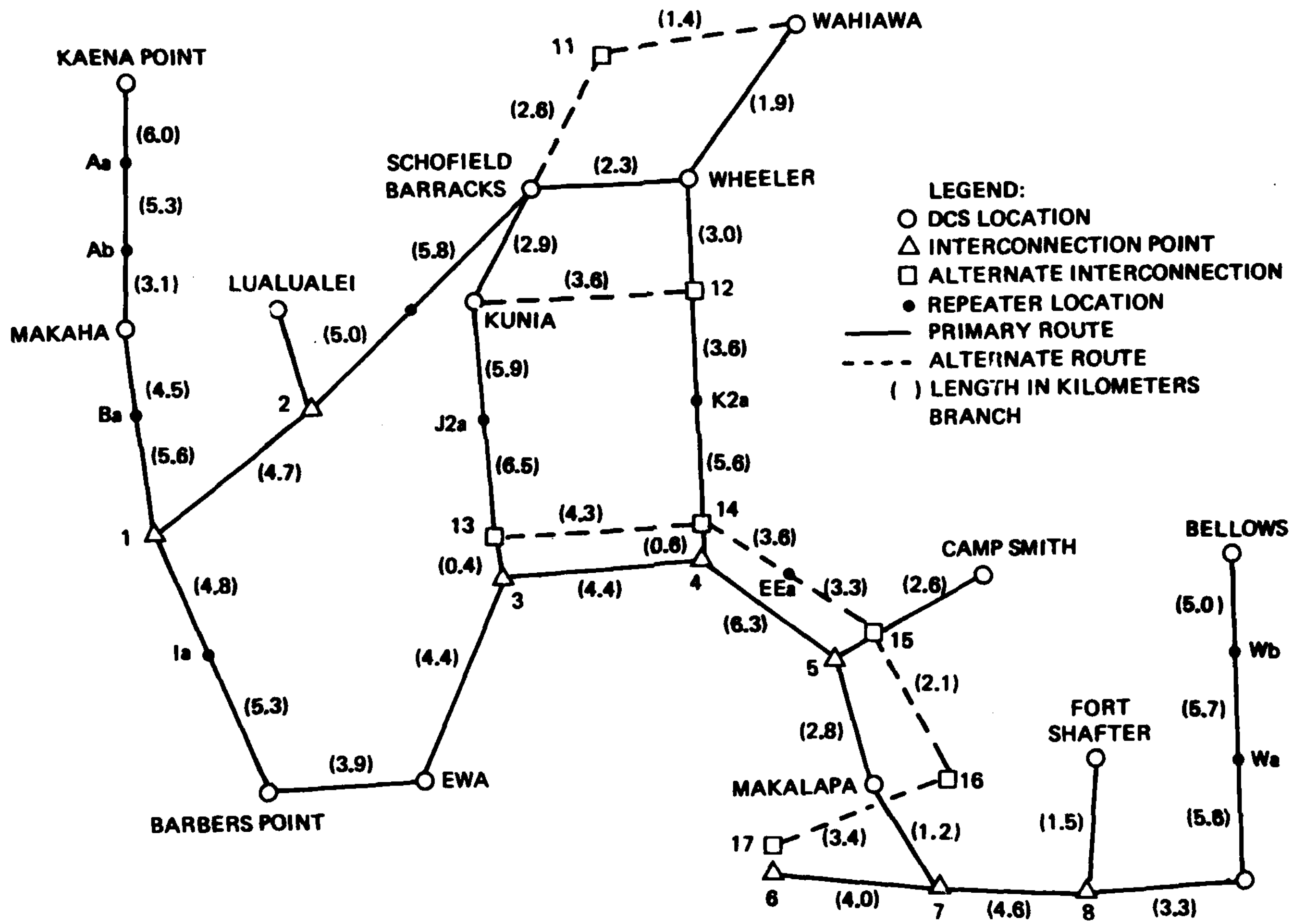


Figure 2.3-2. Candidate Mesh Type Network for Oahu

However, mm-wave frequencies unlike centrimetric frequencies are more subject to various attenuations such as:

1. Absorption due to molecular oxygen and water vapor
2. Attenuation due to rainfall
3. Scintillation fading.

As explained in Section 2.2.3, rainfall rate is a most paramount parameter increasing attenuation in millimeter wave range. For example, for Honolulu the normal annual rainfall, based upon climatological data from 1941 to 1970, is 582 mm. The maximum average rainfall rate observed October 30, 1978, over a period of 3 hours was 15.8 mm/hour. This would result in an excess attenuation of about 4 dB/km. However, rainfall rates as high as 50 mm/hr have been observed in the Honolulu area during a severe rain storm on April 19, 1974. This rain rate yields about 11 dB/km of excess attenuation. Fortunately for communication networks such intense rainfall rates are generally localized to small cells and are of limited occurrence.

Another type of loss which should be considered is scintillation fading. For the mm-wave links under consideration, excess path loss due to scintillation fading is approximately +2 to +3 dB.

As a result, the shorter repeater spacings from 5 to no more than 10 km are required to overcome the inherent space loss and ensure adequate fade margins for expected heavy rainfalls.

2.3.1.2 Alternative System H-2. A buried cable system is proposed as the second alternative transmission system on Oahu Island. Detailed discussion on characteristics and capability of coaxial cable and optical fibers has been documented in Sections A.1 and A.9 of Appendix A, Transmission Media, Final Phase IA Report.

A buried cable system has the following advantages:

1. Insensitive to electromagnetic and radio interference
2. Establishes security and privacy links

3. Unaffected by atmospheric phenomena

4. Allows complete control of the signal intensity along the cable by insertion of repeaters at suitable spacing

5. Eliminates frequency allocation problems

6. Accommodates high data rates.

However, the buried cable system has the following disadvantages:

1. The burial of a cable on private and public land requires permission by the various parties, state and national agencies concerned

2. The cost of implementation is higher than for radio links.

A cable route map is shown in Figure 2.3-3. This figure displays the logical connections of the links, the distance between two nodes, and the number of T1 channels. The total T1 channel-miles of the primary network is 868.9. Since the highest traffic density is concentrated between Wahiawa, Wheeler, Makalapa, Pearl Harbor, Hickam, an auxiliary network is proposed. The total T1 channel-miles of primary and alternative routes is 1684.3.

DS-3 (44.736 Mbps) digital transmission system employing 2.6/9.5 mm coaxial tubes is proposed. One L3 cable with five pair working tube pairs and one spare tube pair can be used for almost half the number of the links with ample growth capability. Two parallel runs of L3 cables will provide needed capability for other links. Needed cables and associated electronics are standard off-the-shelf items.

Another option considered for buried cable systems is to use optical fiber instead of coaxial tubes. The state-of-the-art of optical fiber is moving rapidly. Currently, optical fiber communications systems operating at DS-3 rate using 0.8-0.9 μm is available; however, a longer wavelength system at 1.2-1.3 μm is more attractive from the viewpoint of performance and cost effectiveness. The 1.2-1.3 μm fiber system is proposed for DCS III but technical details of the system cannot be specified at this time because most components associated with a longer wavelength system, particularly fiber, source, and detector, are being developed currently.

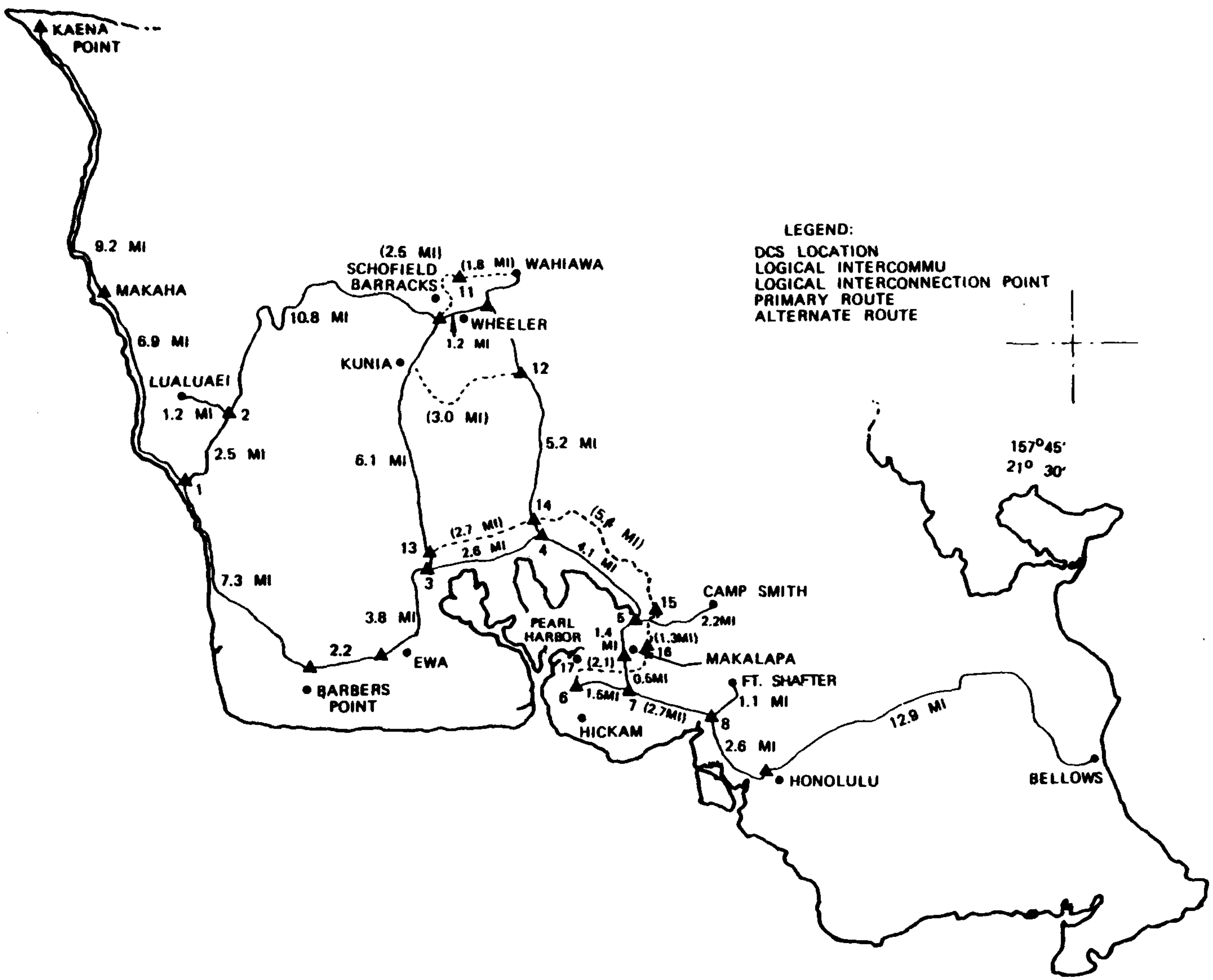


Figure 2.3-3. Actual Cable Routes in Hawaii

2.3.2 Germany. The DCS in West Germany is currently being gradually upgraded and digitalized. The proposed dense area is in central Germany with a size roughly 120 km x 120 km squares. Within the area there are 20 communication nodes and a few repeater stations located at the Rhine River Valley to the rolling terrains. Two alternative systems are proposed for the future DCS III system. They are:

1. Airborne relay system
2. Buried cable system.

2.3.2.1 Alternative System G 1. Two different airborne relay platforms were considered, namely, tethered balloon or aircraft. These platforms are discussed in detail in Sections A.16 and A.14 of Appendix A, Transmission Media of Final Phase IA Report.

Packet radio techniques, which already have demonstrated significant benefits for data communications show promise for secure voice transmission. The airborne relay system proposed works like a low altitude stationary satellite; however, to improve spectrum utilization and system performance the airborne system could be operated as a packet radio network with one broadcasting channel. However, implementation of packet radio airborne relay system or conversion of TDMA airborne system to a packet radio mode of operation has to await the results of on-going EISN programs and some further indepth study.

It is shown from the European Digital Backbone Multiplexing Plan which was used to establish the baseline of the traffic requirement in Central Germany that there are 100 T1 channels and a wideband data between Ramstein and Landstuhl which corresponds to 4 T1 to meet the traffic requirement in the late 1980's and early 1990's. However, this evaluation may not be appropriate for the airborne relay because it is based on the node-to-node traffic capacity. In the airborne relay link, as illustrated in Figure 2.3-4, every communications directly reaches its destination through the relay; one-third of total capacity can meet the requirement without taking waiting time.

The airborne relay can be considered as a low altitude communication [illegible] the multiple access schemes that are used in the present [illegible] the future satellite communication links can also

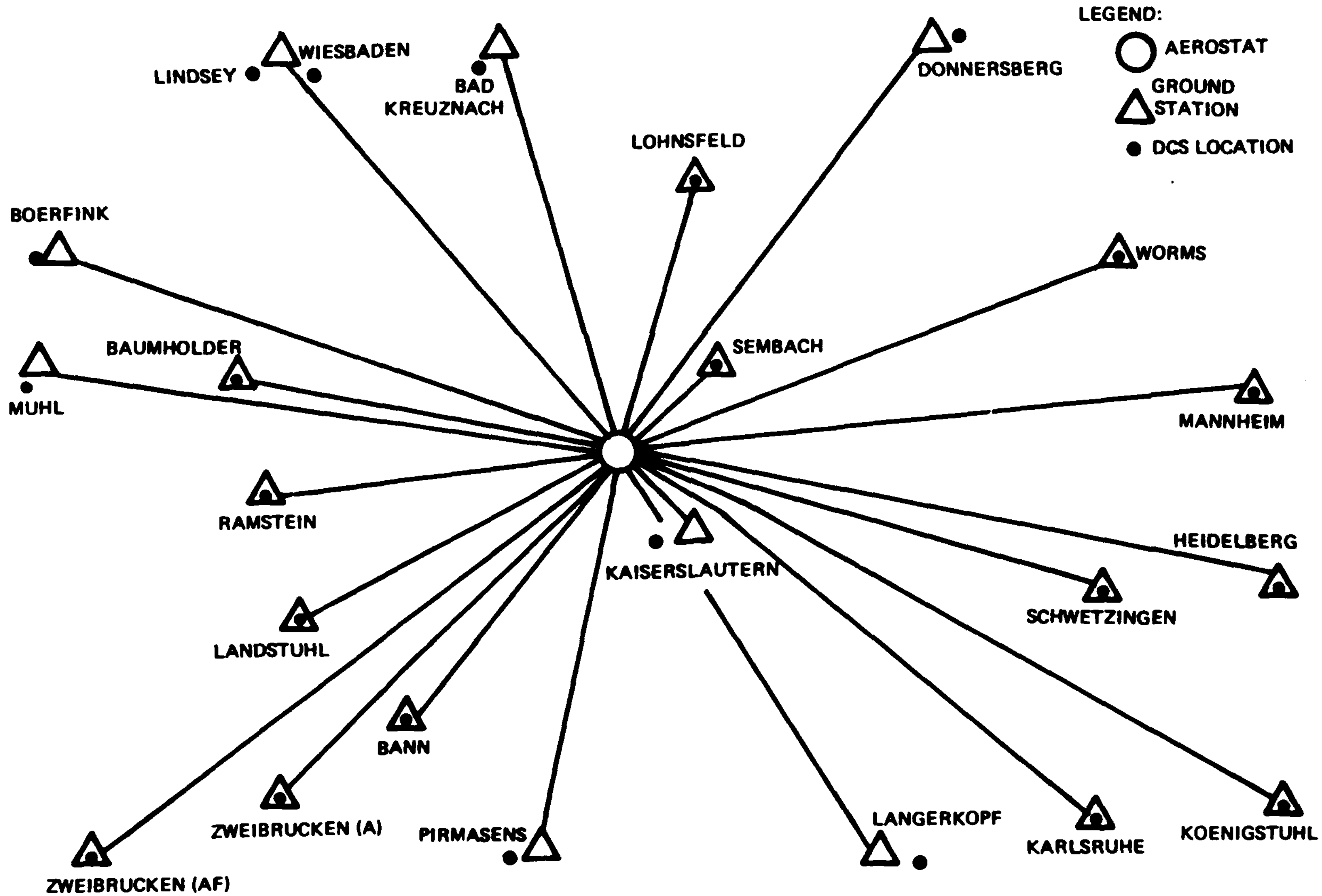


Figure 2.3-4 Airborne Link Connections in Central Germany

be used for the airborne communication links. The time division multiple access (TDMA) and its derivative, the Single-Channel-per Carrier-Demand-Assigned Multiple Access (SCPC-DAMA), are a mature, fully developed system in operation. Although the TDMA needs complex timing and synchronization requirements, it has a great potential for the future communication systems because it does not have the intermodulation problem.

The on-board payload is the local relay point for all the point-to-point communications in the area. Multiple services are simultaneously provided over the entire ground coverage area. Each communication node is assigned to a particular time frame with an appropriate bandwidth based on the capacity requirement of that particular station. The frequencies for the up and downlink are decided as 7 and 8 GHz, respectively, for the attempt to avoid the interference from the other satellite which has 8 and 7 GHz for up and downlink, respectively.

Since the altitude of the airborne is very low compard to the satellite, the beamwidth of the antenna should be very wide, such as 170° for the tethered balloon and 150° for the aircraft and HAPP to cover the entire area. Thus, 3 dB gain is appropriate for the on-board antenna.

2.3.2.2 Alternative System G-2

A buried cable system is proposed as a second alternative system in Central West Germany. The advantages and disadvantages of a buried cable system, discussed in Section 2.3.1.2, Alternative Transmission System H-2, are also applicable here.

The preliminary design for the cable network is shown in Figure 2.3-5. The figure displays the logical connections of the links, the distance between two connected nodes, and the number of T1 channels. The same information is tabulated in Table 2.3-1. From Table 2.3-1, the calculated total T1 channel-miles of the primary network is 3,198. The total T1 channel-miles of the auxiliary is 1,248.5.

The design for the primary network includes only the routing for meeting the required minimum VF circuits. However, an auxiliary network is also proposed which merely increases a few connecting links. The auxiliary network enhances the survivability and flexibility of the system.

Figure 2.3-5. Actual Cable Routes in Central Germany

Table 2.3-1. Cable Link Characteristics (Primary Network)

Link Identification	Location Node 1	Location Node 2	Distance (Miles)	Voice Channels
A	Boerfink	IP 1	5	132
B	IP 1	Baumholder	15	324
C	Baumholder	Ramstein	22	372
D	Ramstein	Landstuhl	3	900
E	IP 6	Landstuhl	8	504
F	Landstuhl	Bann	3	552
G	Bann	IP 4	6	300
H	Zweibrucken (AF)	Zweibrucken (A)	5	48
I	Zweibrucken (A)	IP 2	13	144
J	IP 2	IP 4	13	276
K	IP 4	IP 5	8	276
L	IP 5	IP 3	4	252
M	IP 2	IP 3	15	108
N	IP 4	IP 6	5	156
O	IP 5	IP 8	8	72
P	IP 6	IP 7	3	660
Q	IP 7	IP 8	5	144
R	IP 7	IP 9	7	576
S	IP 9	Lohnsfeld	3	480
T	Lohnsfeld	IP 12	8	96
U	IP 13	IP 14	3	504
V	Lohnsfeld	IP 14	6	348
W	IP 10	IP 11	28	120
X	IP 11	IP 12	16	192
Y	IP 12	IP 13	7	96
Z	IP 14	Worms	21	156
AA	Worms	IP 15	11	168

Table 2.3-1. Cable Link Characteristics (Primary Network, Cont'd)

Link Identification	Location Node 1	Location Node 2	Distance (Miles)	Voice Channels
BB	IP 8	IP 15	23	168
CC	IP 15	IP 16	3	336
DD	IP 16	Schwetzingen	9	372
EE	Schwetzingen	Heidelberg	5	444
FF	Schwetzingen	Karlsruhe	30	144
GG	Heidelberg	Koenigstuhl	8	180

Cable Link Characteristics (Auxiliary Network)

Link Identification	Location Node 1	Location Node 2	Distance (Miles)	Voice Channels
T	IP 21	IP 12	7	444
Y	IP 12	IP 13	7	444
AA	Worms	IP 22	7	168
HH	Bann	IP 17	5	552
II	IP 17	IP 18	2	624
JJ	IP 18	IP 19	9	504
KK	IP 19	IP 20	10	576
LL	IP 20	IP 21	6	480
MM	Lohnsfeld	IP 21	1	96
NN	IP 15	IP 22	4	168
OO	IP 22	Manheim	10	156
PP	Mannheim	Heidelberg	15	204

DS-3 (44.736 Mbps) digital transmission system employing 2.6/9.5 mm coaxial tube is proposed. Since the digital hierarchy of the U. S. is different from that of Europe, an interface unit should be inserted between the U. S. digital systems and the European systems. To install the coaxial cable system, the contract team should consist of U. S firms and German firms for mutual interest, better management and technical information exchange.

One L3 cable with five pairs of working tube pairs and one spare tube pair can be used for almost half the number of links with ample growth capability. Two parallel runs of L3 cable will provide needed capability for other links. Needed cables and associated electronics are standard off-the-shelf items.

The networks discussed are hypothetical and have no relationship to actual or planned DCS capabilities in Central Germany. These networks must only be used as a reference point from which to compare alternative transmission media to demonstrate improvement in performance and/or cost.

2.3.3 Turkey. This subsection provides a description for a baseline system and two proposed transmission systems to be used in Turkey. The two proposed systems are an EHF satellite, designated T-1, and an airborne relay, designated T-2. The area of Turkey is much larger than that of Central Germany but the number of users is relatively small.

Current DCS plans are to upgrade the present system during 1985-1990. The proposed system will make use of digital modulation, as opposed to the analog FDM-FM equipment presently in place. The analog system in place is adequately designed and can accommodate the required channel capacity without severe performance degradation. However, the equipment in place is 20 years old and, in some cases, is antiquated in technology. Thus, the development programs are to provide a new approach, by proposing the use of digital equipment for the new transmission systems. The purpose of the new systems is to replace the analog troposcatter link systems, because of their severe signal degradation due to intersymbol interference from path delays. The new system plan is based on the premise that currently existing channel capacity is sufficient for the new system and no new sites will be necessary.

2.3.3.1 Alternative System T-1. An EHF satellite system is proposed for Turkey. A previous study has shown that better ECM performance can be obtained at higher frequencies but at the highest frequencies technically feasible the links suffer higher attenuation in bad weather. Comparison studies have been done on overall performance of a number of frequency bands and concluded that for ground terminals in temperate climates the optimum frequency bands are 30 GHz for the uplink and 20 GHz for the downlink. Even in a non-jamming environment, these bands offer a number of advantages such as wide bandwidth and narrow beamwidth. This results in a high gain for a small aperture and the higher discrimination provides potentially many more longitudinal slots in the desirable but crowded synchronous equatorial orbit.

Although the alternative presented above has a number of advantages in a benign environment, it has some disadvantages which will be discussed below together with some mitigating factors such as atmospheric attenuation.

Turkey has two climate zones; the coastal regions including terminal locations such as Izmire, Sahin Tepesi, Sinop, and Incirlik have a Mediterranean sub-tropical climate with virtually no rain in the summer. The climate of Elmadag, Dryabakin and Erhai is similar to that of Albuquerque which is generally dry but can have rain any month with a maximum precipitation in the late spring or early summer season. It is necessary to obtain monthly or seasonal precipitation statistics to evaluate the seasonal attenuations which vary significantly from season to season. Monthly rain statistics have been obtained for Albuquerque and Tel Aviv to obtain the appropriate seasonal attenuation probabilities for an evaluation angle of 30 degrees. These values are greater at locations where the elevation angle to the satellite is less than 30 degrees but even at Diyabakir the 20 GHz attenuation for 99.5% of the time is less than 6.7 dB. The total effect, however, due to the high antenna gain available from 30 GHz and 20 GHz antennas and the comparative dry climate in Turkey results in similar performance for the same spacecraft and terminal equipment at either 7.6 GHz or 20 GHz

under moderate rain conditions and better performance at 20 GHz for fine or cloudy weather which is statistically more important. Thus although atmospheric attenuation is greater the next results are better at the higher frequency most of the time, and only slightly worse for less than 1 percent of the time.

It has been shown that although the 30 GHz and 20 GHz bands suffer some disadvantages due to atmospheric loss in bad weather, the losses are reasonable due to the favorable location of Turkey with respect to either of the two available DSCS III positions in the geosynchronous orbits. Moreover, the higher frequencies enable the use of a high gain beam from a comparatively small antenna.

It has also been shown that an EHF SATCOM system using a simple transponder on either the Atlantic or Indian Ocean, the DSCS III is feasible and could provide a 46 Mb/sec capability with a 99 percent availability for the long-haul circuits in Turkey, currently served by large tropo-scatter stations. This capability is significantly greater than estimated requirements and may be used to supply other services such as wide band circuits and replacement of some other troposcatter links. Alternatively, greater availability in bad weather could be achieved and/or smaller antennas used at most of the terminals. Most of the technology is already under active development but some development of the dual beam antenna for optimum coverage from the Indian Ocean satellite may be required.

2.3.3.2 Alternative System T-2. An airborne relay link system is proposed as one of two alternative transmission systems for Turkey. Turkey is very nearly a rectangular shaped country with a land area of about 767,000 km^2. Its east-to-west distance is approximately three times longer than its north-to-south distance. Since the airborne relay link can be considered as low altitude satellite link, the higher altitude it has, the longer line-of-sight is achievable. The altitude of aircraft or HAPP is about 20 km while the altitude of tethered balloon is relatively low, 4.5 km. Thus, it is obvious that the number of relay platforms can be significantly reduced by using the aircraft or HAPPs instead of

tethered balloons. In Turkey two aircraft relay platforms can cover the entire 25 small ground terminals. The airborne relay link connections are shown in Figure 2.3-6. The HAPP has the same altitude as the aircraft, but it is technologically in a preliminary development stage. Therefore, the aircraft is chosen as an adequate relay platform. Since the performance characteristics of an airborne relay platform were already described in Section 2.3.2.1, G-1 Alternative System of Germany, they are not repeated here. The remarkable difference is the east-to-west distance of Turkey is very long, more than 1,000 km, compared to 100 km of Germany. Therefore, it can be summarized that the higher ground terminal antenna gain and transmitter power are required, and one central ground relay station located in Elmadag is needed to relay the messages to the other aircraft relay platform. The frequencies for up and downlink are chosen as 7 and 8 GHz, respectively, with the same reason as described in Section 2.3.2.1.

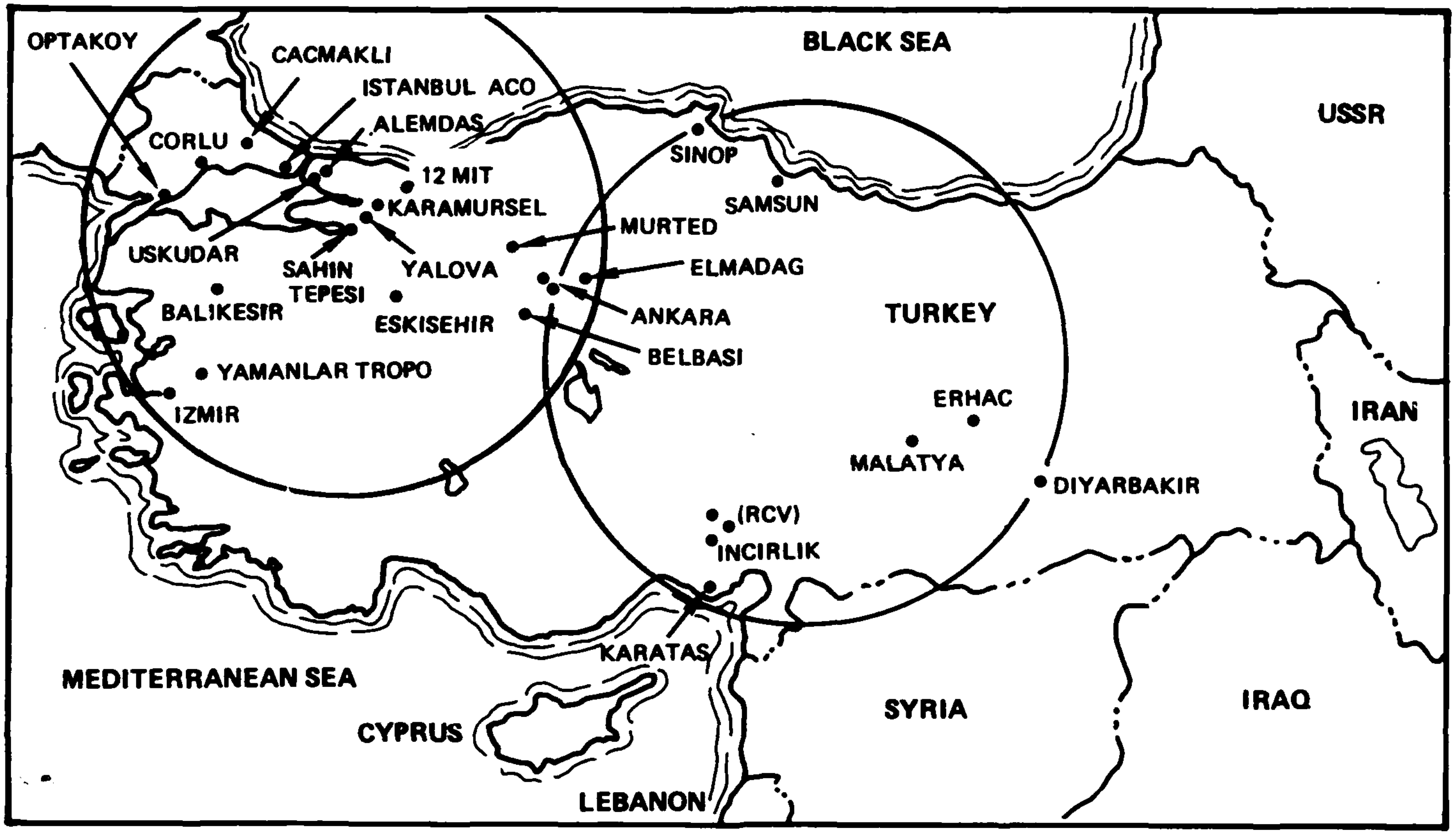


Figure 2.3-6. Ground Coverage of Two Airborne Relays in Turkey

(THIS PAGE INTENTIONALLY LEFT BLANK)

3.0 SYSTEM PERFORMANCE MEASURES

System performance of each of the candidate transmission systems developed in Phase IA effort were evaluated and the results are presented in Section 5 of this report. The performance measures adopted for system evaluation are discussed in this section and the methodologies of evaluation are presented in the next section.

3.1 BIT ERROR RATE AND TIME AVAILABILITY

The performance of a digital communication system is specified by two basic requirements or measures. The first measure prescribes the quality of channels to be provided by the system, assuming the channels are available. The second measure prescribes the availability of channels.

The primary measure of quality of channels is the bit error rate (BER) or bit error probability. BER is a well defined parameter and well understood.

If the channel is assumed not to have dynamic characteristics, average bit error probability alone can be used to measure the system performance. However, it is very difficult to assume that the channel is maintained in a steady state for a long time because of environment variations which cause signal fading, multipath, dispersion, etc. Thus, time availability is needed to specify the short term quality of channel as well as the long term. Availability is defined as the percentage of time the quality of the channel is at least equal to or better than a specified bit error probability. Sometimes, it is convenient to use unavailability instead of availability. Unavailability is simply the difference between unity and availability.

3.2 MEAN TIME BETWEEN LOSS OF BIT COUNT INTEGRITY

Reference 3.2-1 suggests another system performance measure parameter, Meantime to Loss Bit Count Integrity (MTLBCI). MTLBCI may be used to explain synchronization system characteristics. Loss of Bit Count Integrity (BCI) i.e., the accidental insertion of an extra bit or more bits into the bit stream or deletion of one bit or more from the bit

stream, causes loss of synchronization and thus requires resynchronization. The loss of BCI causes an outage or lengthens an already existing outage, and increases the channel error rate during the duration of the loss. However all new DCS crypto equipment can resynchronize within 100 milliseconds for non-secure services and one second for secure voice channel. These values depend on the length of bit sequence. Loss of BCI may occur due to any one of the following four cases (Ref. 3.2-1).

1. Loss of phase lock in receiver bit timing recovery loops.

2. Transmission errors in asynchronous multiplex pulse stuffing control words.

3. Unnecessary resynchronization searches by multiplexers.

4. Switching between unsynchronized redundant units.

Except in the case of the loss of phase lock which contributes a very small percentage of outage, the remaining cases are related to time division multiplexing and pulse (word) stuffing. But the MTLBCI for the typical system is very long such as order of 10^{15} seconds (31.7 million years) (Ref. 3.2-2). Also, test results showed that BCI losses can be reduced significantly by using quadruple diversity operation and increasing fade margin slightly (Ref. 3.2-3).

Since the loss of BCI contributes to cause an outage or to lengthen already existing outage duration by a small amount, the parameter can be absorbed into the availability. Therefore, only bit error rate and time availability are used for system performance measures for this work.

AD-A101 363 TRW DEFENSE AND SPACE SYSTEMS GROUP REDONDO BEACH CA F/G 17/2.1
EVALUATION OF DCS III TRANSMISSION ALTERNATIVES, PHASE 1B. FINA--ETC(U)
SEP 80 T M CHU DCA100-79-C-0044
UNCLASSIFIED TRW-35142 SBIE-AD-E100 403 NL

2 OF 3
AD
A101363

4.0 SYSTEM PERFORMANCE EVALUATION METHODOLOGY

This section describes the performance evaluation methods for each different transmission media listed in Section 2.2. The evaluation derives the relationship between the system parameters and performance parameters to achieve the DCA end-to-end requirements. Since each transmission media has different channel characteristics and advantages for the various climate and topographic conditions, a brief description of these effects on transmission media are provided.

In order to provide system performance criteria from a user's point of view, five ranges of voice communication outages during five minute call and one range of 1000 bit data communication are defined as listed in Table 4.0-1.

Unavailability is provided on an end-to-end (ETE) basis. According to the definition described in the technical report by Kirk and Osterholz (Ref. 3.2-1), the value should be assigned to the global reference circuit which consists of four segments: a leased common carrier segment of 3862 km (2400 miles) length spanning CONUS; two satellite segments of one hop each; and an overseas terrestrial segment of Government-owned LOS and troposcatter facilities 3862 km in length.

From the assumption that unavailability due to equipment failure is greater than that due to climatic effects, a relative unavailability allocation ratio of four to one between the terrestrial segment and the satellite segment has been made because the satellite segment has fewer equipment than the terrestrial segment. The given unavailability 0.01 has been allocated as:

CONUS common carrier segment	4×10^{-3}
Satellite segment #1	1×10^{-3}
Satellite segment #2	1×10^{-3}
Overseas terrestrial segment	4×10^{-3}
TOTAL	10^{-2}

However, two difficulties arise when applying the allocation above directly to DCS III. One is that recent technology improvement trends show the equipment failure rate significantly reduced to a point when

Table 4.0-1. Salient DCS Performance Criteria

VOICE CRITERIA

OUTAGE TYPE	CRITERIA	FADE OUTAGE PROBABILITY PER CALL MINUTE	
		12,000 MILE GLOBAL REFERENCE CKT.	600 MILE REF. VF OR DATA CKT.
I(3)	FOD(1) < 200 m. sec	not specified (NS) (trivial)	NS
II(3)	200 m. sec < FOD < 5 sec	0.02	0.0025(5)
III(3)	5 sec < FOD < 60 sec	0.002	0.00025(5)
IV(3)	For any FOD 2/min < FOR(2) < 5/min	0.01	0.0025(5)(7)
		PROBABILITY THE SYSTEM IS UNAVAILABLE	
V(4)	1/min < FOD or 5/min < FOR	0.01 TOTAL a. 0.004 CONUS Terrestrial b. Satellite (2) c. 0.004 OCONUS Terrestrial	0.001 TOTAL a. 0.0001 14 LOS hops b. 0.0001 1 Tropo hop c. 0.0008 Equipment

DATA CRITERIA

VI	ERROR FREE PROBABILITY (1000 Bit Block)	.99	.99937

Notes:
1 Fade Outage Duration
2 Fade Outage Rate
3 These are signal quality criteria (short term phenomenon)
4 This is a system unavailability criteria (long term phenomenon)
5 There are eight 600 mile circuits in the 12,000 mile global reference circuit
6 MIBFO mean time between fade outage - MTTR mean time to repair - MTSR mean time to service restoral
7 Considering no tropo in CONUS

compared to unavailability due to climatic effects. The other difficulty is that DCS III is not concerned with long ranges such as a 20,000 km (12,000 mile) gobal circuit. Thus, an unavailability of 10^{-3} rather than 10^{-2} is assigned to each area or country.

4.1 COAXIAL CABLE SYSTEM

Performance evaluation methods of the coaxial cable transmission system is presented in this section. The system performance is specified by two basic parameters. The first prescribes the quality of channels to be provided by the system, assuming the channels are available. The primary measure of quality is bit error rate. The second parameter prescribes the availability of the channels. The availability is defined as that time portion which the received signal level (RSL) corresponding to a specified bit error probability is maintained.

4.1.1 Coaxial Cable for Digital Transmission

Coaxial cable transmission system for digital signals has been in service for many years. Table 4.1-1 shows the main characteristics of the systems developed for coaxial cables.

In digital transmission, analog inputs are filtered, sampled and encoded to form a basic digital stream and then multiplexed with other data at the appropriate multiplexing levels. If the input data is already digital, it will be synchronized with the operating system and then multiplexed with many other data streams. The data rate at different points in the system are organized according to the hierarchy of the digital system used.

The typical hierarchy of digital channels used in the USA is shown in Figure 4.1-1. The basic input is the 64 kb/s PCM voice channel and the first or primary PCM multiplexer operates at a bit rate of 1.544 Mbps for 24 voice channels. After 3 more levels of multiplexing, the final output data stream is at 274.176 Mbps corresponding to 4032 voice channels. The highest USA bit rates 274.176 Mbps of DS4 level is shown in the table, however, low rate circuits at DS1, DS2, and DS3 levels are also operational.

Table 4.1-1 Digital Coaxial Cable Systems

	EUROPE					U.S.A.	CANADA	JAPAN	
BIT RATE Mbps	8.448	34.368	120.00	139.264	139.264	274.176	274.176	97.728	400.352
TUBE SIZE (MM)	0.7/2.9	0.7/2.9	1.2/4.4	1.2/4.4	1.2/4.4	2.6/9.5	2.6/9.5	1.2/4.4	2.6/9.5
TYPE OF REPETITION	REGENER.	REGENER.	REGENER.	HYBRID	REGENER.	REGENER.	REGENER.	REGENER.	REGENER.
MAXIMUM DIGITAL REPEATER SPACING (KM)	4.1	2.05	2.1	80	2.05	1.74	1.9	1.6	1.6
MAXIMUM ANALOG REPEATER SPACING (KM)	NO	NO	NO	2.05	NO	NO	NO	NO	NO
LINE CODE	HDB3	MS43	4B3T	CLASS IV P.R. (7 LEVELS)	MS43	BINARY	B3ZS	AMI + SCRAMBLER	AMI + SCRAMBLER
POWER FEEDING CURRENT (MA) VOLTAGE (V)	50 $\pm$ 400	100 $\pm$ 400	50 $\pm$ 250	100 $\pm$ 400	-	-	870 $\pm$ 1500	250 $\pm$ 350	550 $\pm$ 1500
POWER FEEDING SPAN (KM)	80	80	30	80	100	-	208	24	100
DESIGN ERROR RATE	2.5×10^{-10} PER KM	10^{-10} PER KM	2×10^{-7} FOR 2500 KM	10^{-10} PER KM	10^{-10} PER KM	-	10^{-7} FOR 2500 KM	10^{-8} FOR 200 KM	10^{-7} FOR 2500 KM
TYPE OF APPLICATION	SHORT & MEDIUM HAUL TRUNKS	SHORT & MEDIUM HAUL TRUNKS	INTERCITY TRUNKS	INTERCITY TRUNKS	INTERCITY TRUNKS	METROPOLITAN AREAS	INTERCITY TRUNKS	INTERCITY TRUNKS	INTERCITY TRUNKS
IMPLEMENTATION DEGREE	IN SERVICE	EXPERIM. LINK	EXPERIM. LINK	EXPERIM. LINK	UNDER DEVELOP.	IN SERVICE	IN SERVICE	EXPERIM. LINK	EXPERIM. LINK

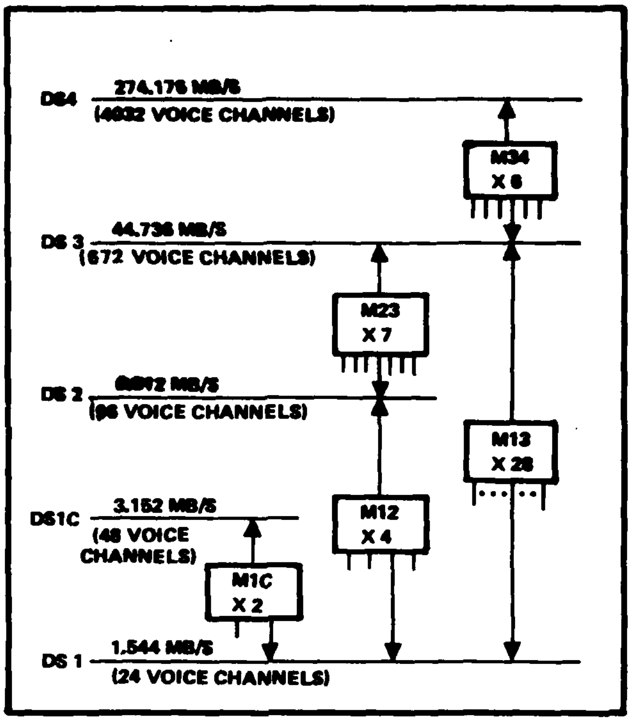


Figure 4.1-1. U. S. Digital Multiplex Plan

4.1.2 Bit Error Rate

The bit error rate of a coaxial cable transmission system is determined by cable and repeater characteristics. They are discussed in this section along with link analysis.

4.1.2.1 Regenerative Repeaters. Regenerative repeaters are used at regularly spaced intervals along with digital transmission line to reconstruct the digital signal, thereby eliminating the effects of accumulated noise and distortion.

Performance of a regenerative repeater shown in Figure 4.1-2 is measured by its error rate. The relationship between error rate and other system parameters such as signal-to-noise ratio, bandwidth, and number of transmitted levels are examined. The eye diagram (Ref. 4.1-1), a technique for the quantitative evaluation of error rate, is introduced.

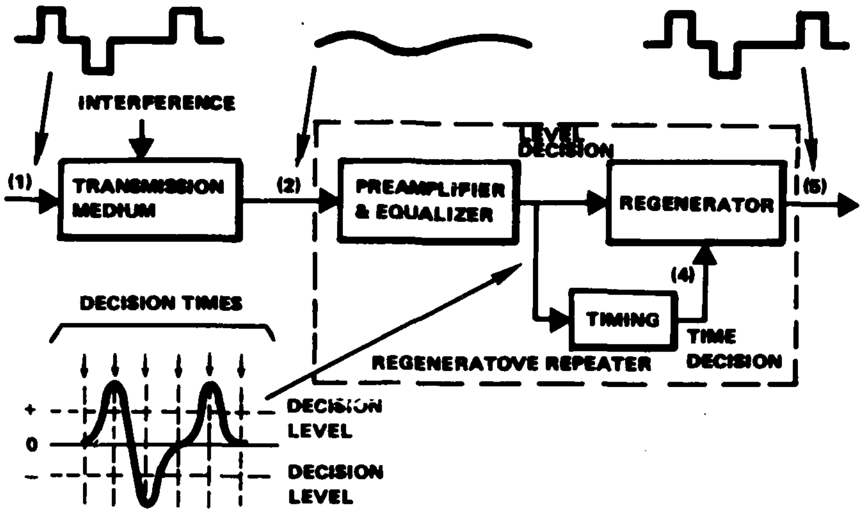


Figure 4.1-2 . Regenerative Repeater

4.1.2.2 Error Performance with Gaussian Noise

First, consider the case in which either positive or negative pulses (polar binary signals) of amplitude + V_p or - V_p with equal probability are received as shown in Figure 4.1-3. V_n denotes the received signal voltage.

The error probability is

$$P_e = \frac{1}{2} \text{ Prob } (V_n < V_p) + 1/2 \text{ Prob } (V_n > -V_p)$$

$$= \frac{1}{2\pi\sigma_n} \int_{V_p}^{\infty} \exp\left[- V_n^2 \Big/ 2\sigma_n^{\ 2}\right] dV_n$$

$$= \frac{1}{2} \text{ erfc } \left(\frac{V_p}{2\sigma_n}\right) \qquad (4.1\text{-}1)$$

where σ_n is the r.m.s. value of the noise and erfc is the complementary error function. This relationship between probability of error for random

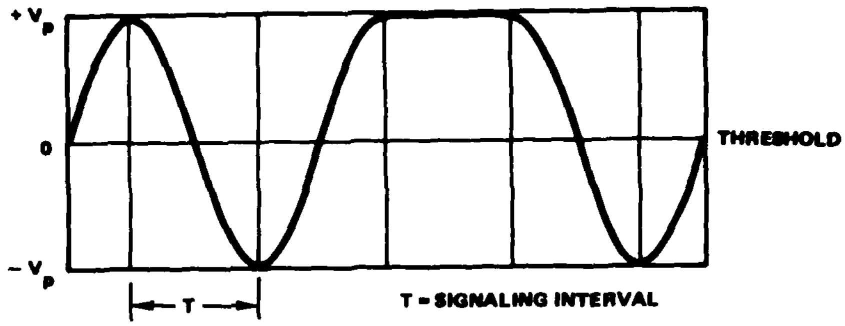


Figure 4.1-3. Random Polar Binary Pulses

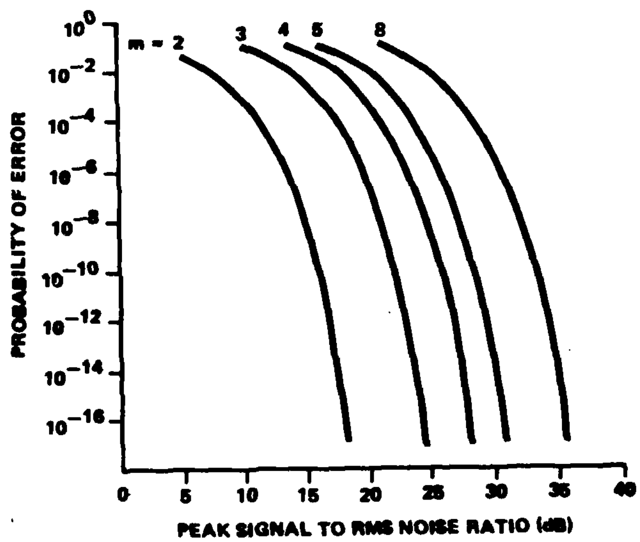


Figure 4.1-4. Probability of Error Versus Peak Signal to rms Gaussian Noise for Random m-level Polar Transmission

polar binary signal and peak signal to r.m.s. Gaussian noise (S/N) ratio is plotted in Figure 4.1-4 as the curve labeled m = 2, where m indicates the number of signal levels. To achieve a probability of one error in 10^{10} symbols which is a typical repeater section requirement, a S/N ratio of approximately 16 dB is needed. Consider the transmission of pulses which can take on with equal probability any of m-levels rather than just two amplitude levels. These levels are equally spaced from $+V_p$ to $-V_p$ as shown in Figure 4.1-5. The probability of error for polar m-ary signal is given by

$$P_e = \frac{m-1}{m} \operatorname{erfc}\left[\frac{V_p}{(m-1)\sqrt{2}\,\sigma_n}\right] \qquad (4.1\text{-}2)$$

This expression is plotted in Figure 4.1-4 for various values of m. In Figure 4.1-6 the difference is illustrated for a digital transmission system with regeneration and for another system without regeneration where the S/N requirement for each repeater section is given as a function of the total number of sections. The advantage of regeneration indicated in Figure 4.1-6 is obtained at a large increase in cost.

4.1.2.3 Error Rate with Non-ideal Eyes

A convenient graphical technique for determining the effects of the practical degradations introduced into the pulses as they travel to the repeater is the eye diagram. Such an eye diagram is given in Figure 4.1-7 for a ternary system in which the individual pulses at the input to the repeater have the cosine square shape illustrated in Figure 4.1-7b. The decision area of "eye" for each of the two decision levels is evident.

The various practical repeater section degradations shrink the ideal eyes. The additional S/N requirement to maintain the error rate is a function of the amount of degradation and the number of levels.

The degradations usually fall into the two categories of amplitude and timing, corresponding to vertical and horizontal displacement. To obtain the shrunken eye, the amplitude degradations such as intersymbol

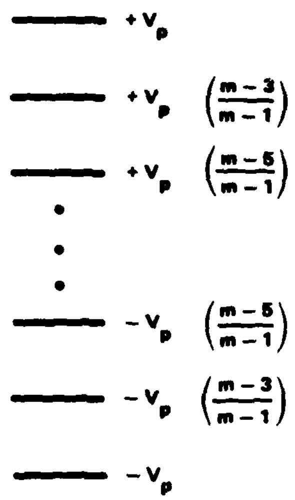


Figure 4.1-5. Amplitude Levels for Polar M-ary

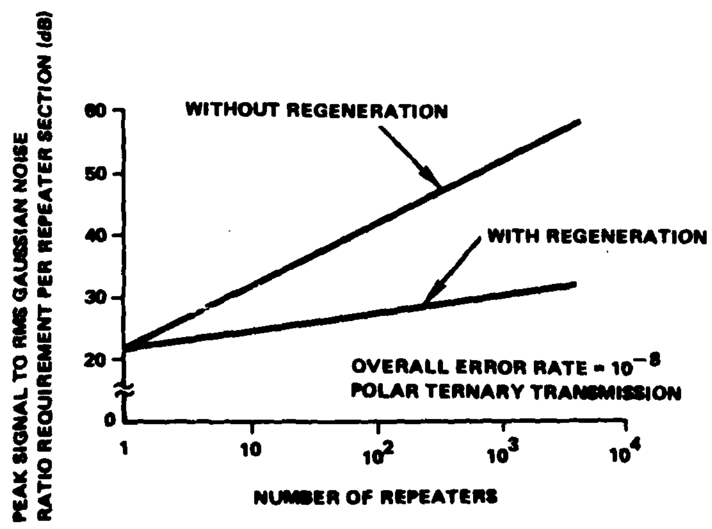


Figure 4.1-6. Noise Accumulation Advantage of Digital Transmission

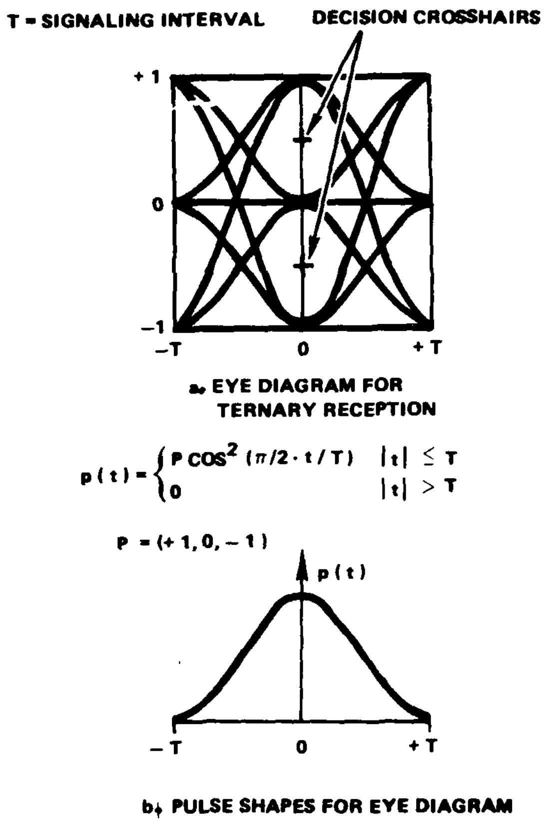


Figure 4.1-7. Eye Diagram

interference, echoes, repeater output variations, and decision threshold uncertainties are summed. This sum is referred to as ΔA. The boundaries of the eye are then shifted vertically, as shown by the arrows in Figure 4.1-8 to account for these amplitude degradations. Next, the timing degradation misalignment and jitter are summed. This sum is referred to as ΔT. The boundaries of the eye then are displaced horizontally, as shown in the Figure 4.1-8. A technique for evaluating degradations is the eye degradation plane. With ΔA and ΔT as coordinates, contours along which S/N is a constant can be plotted. Figure 4.1-9 shows such contours for a polar ternary and a polar quarternary system in which the pulses at the input to the repeater have the shape illustrated previously in Figure 4.1-7. The combinations of ΔA and ΔT which completely close the eye are given by the curve labeled S/N = ∞

4.1.2.4 The Characteristics of 2.6/9.5 mm Coaxial Cable

The standard Bell System armoured 2.6/9.5 mm coaxial cable is proposed for the DCS III System. The characteristics of 2.6/9.5 mm coaxial cable pairs will be discussed.

1. Type of Coaxial Pair

The center conductor is a solid copper wire of 2.6 mm diameter. The outer conductor consists of a soft copper tape, 0.25 mm thick, formed into a cylinder around the insulation, the axis of this cylinder being the axis of the center conductor; the interior diameter of the outer conductor is 9.5 mm.

2. Charateristic Impedance

The impedance characteristic of the coaxial pair follows a well-defined law depending on frequency, given by

$$Z = 74.4 \left[1+(1-j)\,\frac{0.0123}{f}\right] \text{ ohm} \qquad (4.1\text{-}3)$$

where f is the frequency measure in MHz.

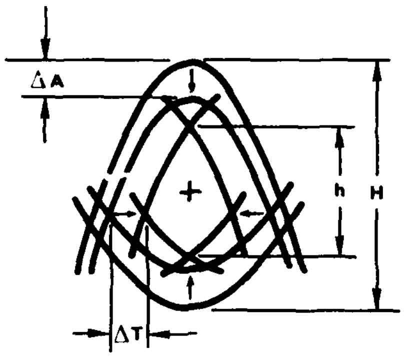


Figure 4.1-8. Shrinking the Eye to Account for Practical Degradations.

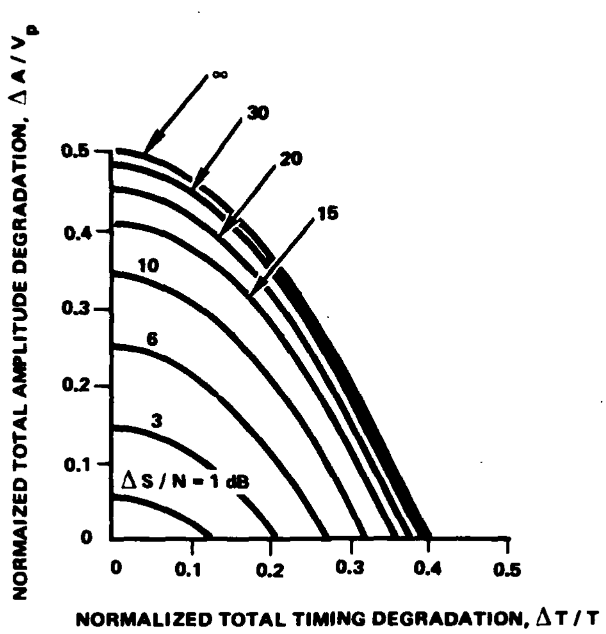
The value of 74.4 ohms (impedence at infinite frequency)is subject to a tolerance of $\pm$ 1 ohm.

3. Attenuation

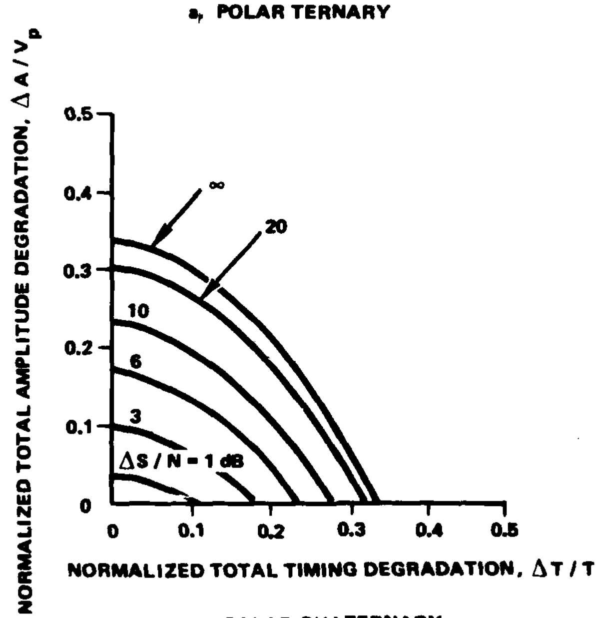
The rate of the variation of the attenuation with frequency, for a nominal value, is indicated in Table 4.1-2.

Table 4.1-2 Attenuation Versus Frequency of 2.6/9.5 mm Coaxial Cable

Frequency (MHz)	0.06	0.3	1	4	12	20	40	60
Attenuation (dB/km)	0.59	1.27	2.32	4.62	8	10.35	14.67	18.0



a. POLAR TERNARY



b. POLAR QUATERNARY

Figure 4.1-9. Eye Degradation Contours

4.1.2.5 Link Analysis

A typical coaxial cable transmission system is shown in Figure 4.1-10. The amplifier power coupled into the transmission cable is given by

$$P_t = P_a - L_t \quad \text{(in dB)} \qquad (4.1\text{-}4)$$

where P_a is the transmitter power

L_t accounts for any coupling losses between the transmitter and the cable.

P_t is the transmission power.

Cable attenuation losses are typically stated in decibels per unit length of cable and include both the attenuation loss and added losses due to amplitude and time degradation. If the cable has a length D km and an attenuation loss factor of α dB/km, then the input decibel power is reduced by αD dB to give the cable output decibel power.

The power coupled out of the cable and into the receiver front end (or repeater) is then further reduced by the coupling loss L_r. Thus for coaxial cable channels, the power flow equation becomes

$$P_r = p_a - L_t - \alpha D - L_r \quad \text{(in dB)} \qquad (4.1\text{-}5)$$

where P_r is the received power.

The receiver signal to noise ratio is expressed by

$$SNR = P_r - N_o B \quad \text{(in dB)} \qquad (4.1\text{-}6)$$

where N_o is noise density function and B bandwidth.

From Figure 4.1-4, the error probability P_e can be computed very easily for any given SNR. The error probability, P_n, for N similiar tandem links is approximately given by

$$P_e \simeq NP_e \qquad (4.1\text{-}7)$$

where P_e is the error probability for each link. Thus, a PCM system consisting of N tandem identical links, has N times the error probability of a single link.

Figure 4.1-10. Cable Transmission System

4.1.2.6 Time Availability

The coaxial system has the following characteristics:

1) Insensitive to external electromagnetic and radio interference.

2) Unaffected by atmospheric phenomena such as rainfall, precepitation and lightning.

Long-term link outage due to electromagnetic and atmospheric interference are very rare on coaxial cable systems.

The major contribution to total unavailability is expected to be equipment failure and cable damage (Ref. 3.2-1, Ref. 4.1-2). The major elements which affect equipment-related unavailability are:

1) The degree of equipment redundancy in the system

2) The efficiency of performance monitoring techniques to detect and switch to standby equipment when failures occur, and

3) The logistics approach that is used to affect the restoral of failed equipments.

Of these factors, the most important is the degree of redundancy. Effectively used redundancy allows nearly uninterrupted service when a single equipment fails.

The next most important factor in optimizing availability is the selected logistics approach. An adequate supply of spare modules or assemblies must be available on-site to avoid excess down time after a failure occurs. Personnel must be available to make the corrective action. Also, travel time is a very important factor in determining the mean-time-to-service-restoral (MTSR). (Note the MTSR includes travel time and time to locate the appropriate part, plus the mean-time-to-repair (MTTR)).

The third major factor affecting unavailability is performance monitoring effectiveness. Performance monitors must be capable of detecting the failure of on-line redundant units and switching to the off-line unit.

The above factors result in equipment-related availability being described in terms of four parameters:

1) The mean-time-between-outages (MTBO) which can be restored by manual redundancy switching,

2) The mean-time-between-outages (MTBO) which require equipment repair to restore service,

3) The mean-time-to-service-restoral (MTSR) when an operational redundant unit is available, and

4) The mean-time-to-service-restoral (MTSR) when actual equipment repair is required.

In summary, the major factors which affect the unavailability of a system such as the DCS which widely uses redundancy are the percentage of undetected off-line equipment failures which nullify the advantage of redundancy, the manning density of the maintenance function which determines the travel time component of MTSR, and the adequacy of spare parts supported.

Table 4.1-3 (Ref. 3.2-1) is an example which illustrates the methodology to determine link unavailability. The postulated link is the link which provides the worse case analysis for time availability. The values and equipment shown are for reference only and may not reflect the actual system to be evaluated. The values used for actual computation are selected according to the system under consideration.

Table 4.1-3. Reference Channel Unavailability

EQUIPMENT	QUANT. (a)	NO. OF CHANNELS AFFECTED (b)	MEAN TIME TO RESTORE SERVICE (HRS) (c)	CHANNEL OUTAGE/ OUTAGE (HRS) (d = bxc)	BETWEEN OUTAGES (HRS) (e)	RATE/ UNIT* ($f=10^6/e$)	TOTAL OUTAGES* (g=fxa)	OUTAGE (HRS)* (h=gxd)
TRANSCEIVER	30	240	2.17	520	125,000	8	240	124,800
A/D CONVERTER	20	120	1/2	60	200,000	5	100	6,000
D/A CONVERTER	20	120	1/2	60	200,000	5	100	6,000
MULTIPLEXER	120	20	1/2	10	220,000	4.5	540	5,400
ENCRYPTION DEVICE	24	20	1/2	10	7,000	143	3,432	34,320
REPEATER	480	1	1/2	1/2	170,000	6	2,880	1,440
STATION POWER**	16	240	1.75	420	500,000	2	32	13,440
TOTAL CHANNEL HOURS/MILLION HOURS					2.4×10^8	TOTAL:		191,400
TOTAL CHANNEL HOURS OUTAGE/MILLION HOURS					191,400			
UNAVAILABILITY					.0008			

* PER MILLION OPERATING HOURS

** THE ASSUMED MEAN-TIME-BETWEEN-OUTAGES FOR STATION POWER IS BASED ON THE UNIVERSAL APPLICATION OF UNINTERRUPTABLE POWER SOURCES (UPS) AT ALL SITES. THE STANDARD UPS PROVIDES BACKUP ROTARY GENERATION CAPABILITY WITH A BATTERY PLANT TO CARRY THE STATION LOAD DURING THE GENERATOR STARTUP PERIOD.

4.2 LINE-OF-SIGHT TRANSMISSION SYSTEM

The system performance evaluation methodology for line-of-sight (LOS) digital radio links for DCS III is discussed in this section. Since LOS is planned to be operated in millimeter wave range, the performance evaluation methodology will be extended up to 35 GHz. Detailed characteristics of LOS system are well documented in Section A.4, Terrestrial Microwave Line-of-Sight (LOS) Transmission, and Section A.6, Millimeter Wave Technology of Appendix A, Transmission Media, of the Final Phase IA Report.

4.2.1 Fade Margin Evaluation. Probability of fade outage replaces the RF link design criterion termed unavailability (Reference 3.2-1). Fade outage is defined as a Received Signal Level (RSL) below the threshold which experiences a fading. As listed in Table 4.0-1, radio links experience three different types of outages for voice communication and one type for data transmission. Fading is caused by two major effects, terrain and climate. In order to make an effort to protect or to reduce terrain caused fading, the following design plans are necessary:

a. Sites are subjected to be in line-of-sight of each other.

b. Frequency bands are chosen by considering legal restraints and frequency interference from other sources.

c. Radio tower heights are determined with consideration of path clearance: all top-to-bottom beam paths and the beam path between the single antennas at the end of the link maintain 0.3 Fresnal zone clearance for K=2/3 for space diversity and nondiversity, respectively, where K is the effective earth's radius factor.

Since a path is assumed to have adequate terrain clearance, the other effect, climate is of greater importance to the design of transmission systems. There are several phenomena induced by the atmosphere in line-of-sight such as filtering, multipath fading, power fading, etc. However, we assume that the radio link channel is not affected by filtering which causes inherent nonuniform frequency delays and phase distortion of the carrier waveform. Power fading can be reduced by

increasing transmitter and antenna gain. Consequently, the entire fade outage considerations due to climate is applied to multipath fading.

In contrast to the short-term effect described above, long-term effect is caused by equipment failure. Current reliability records show that equipment failure are gradually being reduced due to device technology improvement. In order to protect a radio link from channel disturbances or to reduce outages caused by multipath fading, a fade margin should be considered in the system design.

A fade margin is defined as the difference, in dB, between the median unfaded received signal level and the threshold received signal level corresponding to 10^{-4} bit error probability. The probability that the received signal level is below threshold on a space diversity RF link can be expressed in terms of fade margin (Reference 3.2-1, 4.2-1).

$$P_o = \left(r^2 + \frac{1}{r^2}\right)\frac{acD^4}{56S^2}\,10^{-F/5} \qquad (4.2\text{-}1)$$

where

P_o = the probability that the received signal is below threshold

a = the percentage of the year that constitutes the fading season

c = climate and terrain factor. This parameter varies for terrain and climate conditions:

$$c = \begin{cases} 4 & \text{over water} \\ 1 & \text{average terrain and climate} \\ 1/4 & \text{mountains and dry climate} \end{cases}$$

D = path length in statute miles

S = antenna separation (diversity) in feet (S<50 feet)

F = fade margin in dB

r^2 = diversity combiner hysteresis ratio ($10 \log r^2$ = hysteresis ratio in dB. This is the difference in diversity signal level required for the diversity switch to operate).

This equation is based on the diversity improvement experiment for frequency up to 8 GHz. Thus, it may lead to small error for the extended frequency band. Also, the equation is restricted for the path length 14-40 miles. The terrain and climate factor, c, incorporates the effects of both

terrain and humidity. Terrain roughness is calculated from terrain heights above a reference level obtained from the path profile at one-mile intervals, as shown in Figure 4.2-1.

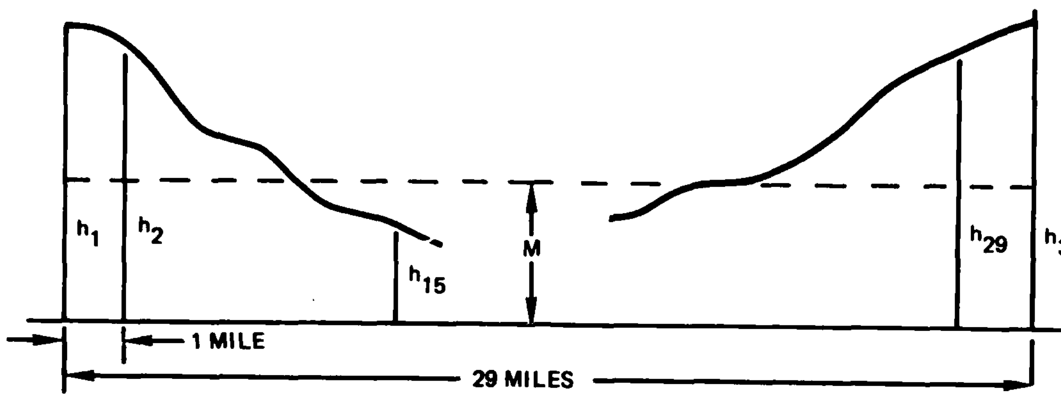


Figure 4.2-1. Determination of Terrain Roughness

Terrain roughness which can be called a standard deviation is the square root of the average square of the deviation from the mean.

$$W = \sqrt{\frac{1}{30} \sum_{i=1}^{30} (h_i - M)^2}$$

$$M = \frac{1}{30} \sum_{i=1}^{30} h_i \qquad (4.2\text{-}2)$$

Modified for roughness, it becomes

$$C = 2(W/50)^{-1.3} \quad \text{coastal areas}$$

$$C = (W/50)^{-1.3} \quad \text{average climate} \qquad (4.2\text{-}3)$$

$$C = 0.5\,(W/50)^{-1.3} \quad \text{dry climate}$$

The hysteresis ratio, r^2, is unity in the absence of hysteresis and becomes larger than unity in the presence of hysteresis. It occurs at comparative switching, which is illustrated in Figure 4.2-2.

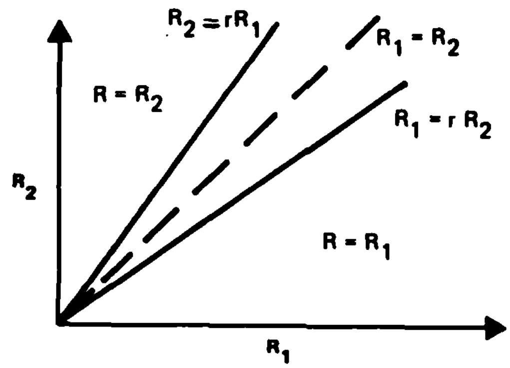


Figure 4.2-2. Comparative Switching with Hysteresis

Where: R_1 and R_2 are the received signal envelop, and R is a composite of R_1 and R_2 by switching. The parameter, a, is expressed as:

$$a = \frac{\text{annual time below the threshold}}{\text{1 year}} = \frac{(t/50)\ 8\times10^6 \text{ sec}}{3.1536 \times 10^7 \text{ sec}} \quad (4.2\text{-}4)$$

where t denotes the average annual temperature of the locality in ^oF. For frequency diversity, s^2 is replaced by

$$S^2 = 112\ Dx\Delta f/f^2 \quad (4.2\text{-}5)$$

where f is a frequency separation in MHz. These results are obtained empirically (Reference 4.2-1, 4.2-2).

Average fade duration may be obtained from the fact that the two received signals R_1 and R_2 are jointly distributed as Rayleigh probability density function, and represented as $\frac{L}{c}$ and $\frac{L}{2c}$ for nondiversity and diversity reception, respectively. The constant c has been obtained as

$$c = 2.22 \times 10^{-3} \text{ sec}^{-1} \quad (4.2\text{-}6)$$

and L represents the fade depth compared to normal signal level.

Thus, the average fade duration time is expressed in terms of fade margin as

$$t_o = 0.141\ g(D)^{\frac{1}{2}}\ 10^{-F/20} \tag{4.2-7}$$

where g = 250 at 15 GHz and g = 200 at 35 GHz.

Rice suggested the probability that t/t_o is larger than a number u can be described as an exponent empirically.

$$P[(t/t_o) < u] = \exp(-1.15u^{2/3}) \tag{4.2-8}$$

where t_o is the mean value to t. Thus, the probability that a fade has a duration of t seconds or greater can be obtained by changing the parameter of (4.3-8) directly

$$p(t) = \exp[-1.15(t/t_o)^{2/3}] \tag{4.2-9}$$

The mean-time-between-fade-outages (MTBFO) in seconds can be obtained from (4.2-1) and (4.2-7).

$$\text{MTBFO} = \frac{(1-P_o)}{P_o} \approx \frac{1.26 \times 10^4 S^2}{\left(r^2 + \frac{1}{r^2}\right) acD^4} \times 10^{0.15F} \tag{4.2-10}$$

The MTBFO in seconds for any particular range of fade duration is givern by

$$\text{MTBFO}(t_1,t_2) = \frac{\text{MTBFO}}{p(t_1) - p(t_2)} \tag{4.2-11}$$

where t_1 and t_2 are the lower and upper duration time limits.

The number of MTBFO per call minute is given by

$$n = \frac{60}{\text{MTBFL}(t_1,t_2)} \tag{4.2-12}$$

By substituting equations (4.2-7), (4.2-9), (4.2-10) and (4.2-11) into (4.2-12) n assumes

$$n = \frac{60\ P_o[e^{-1.15\left(\frac{t_1}{t_o}\right)^{2/3}} - e^{-1.15\left(\frac{t_2}{t_o}\right)^{2/3}}}{t_o} \tag{4.2-13}$$

Since MTFBO is usually much larger than 60, n can be set to be equal to the probability of fade outage per call minute.

The fade margin in dB can be obtained from the following relationship, which is converted into metric units

$$F = -5 \log_{10} \left[\frac{4047\ s^2\ n}{\left(r^2 + \frac{1}{r^2}\right) acD^4} \right] \qquad (4.2\text{-}14)$$

Note that range V in Table 4.0-1 is regarded as unavailability, and range IV is considered not to occur at LOS. Thus, equation (4.2-14) actually explains ranges II and III. But range III outage requires greater fade margin. Therefore, the radio link should be designed with the requirement of range III.

4.2.2 System Gain. System gain is defined as the algebraic difference between the transmitter output power and the received signal strength for the bit error probability of 10^{-4}. For the operating frequency up to 10 GHz, the required system gain is given by

$$G_s = L_s + F + L_w - G_t - G_r \quad \text{(dB)} \qquad (4.2\text{-}15)$$

where L_s = free space path loss

= 92.5 + 20 log f (GHz) + 20 log D (Km)

F = fade margin

L_w = total waveguide loss

L_m = miscellaneous losses due to atmospheric absorption, waveguide againg, receiver figure aging, etc. = 6 dB

G_t, G_r = transmitter and receiver antenna gain, respectively.

There are also other parameters affecting path loss such as transmitter and receiver antenna coupling losses, radiation loss of the transmitting antenna, etc., but these are small enough to be neglected or assumed to be well enough arranged not to cause attenuation.

In the millimeter wave link, there are additive atmospheric effects which can be neglected below 5 GHz operating frequency such as rainfall, water vapor, and various kinds of gases in the system gain evaluation. Since detailed explanations are provided in Appendix C Regional Considerations and Characterization of the Final Phase IA Report, duplicate explanations are avoided here except for a few diagrams with brief descriptions which are necessary for an evaluation of the system gain.

1. Absorption by Water Vapor and Oxygen. In a clear weather condition, a transmitted wave is mainly attenuated by water vapor and oxygen because of various molecular resonances. The attenuation, L_o, may be expressed as

$$L_o = (\gamma_{oo} + \frac{\rho}{7.5} \gamma_{wo}) \quad (4.2\text{-}16)$$

   where γ_{oo} and γ_{wo} are the absorption coefficients (dB/km) for oxygen and water vapor found in Figure 4.2-3, ρ is water vapor concentration (g/m^3) found from CCIR report (Reference 4.2-5), and D is the path length (km). Below 100 GHz, the seriously restricted frequency ranges imposed by water and oxygen are 22 and 60 GHz, respectively. Thus, good choices of frequencies for millimeter wave link are 15, 35, and 90 GHz ranges.

2. Rainfall Attenuation. The attenuation of millimeter wave by rainfall exceeds the combined oxygen and water absorption. When a transmitted wave is incident upon a water drop, it is scattered or absorbed. In centimeter waves, scattering is dominated, but in millimeter waves, absorption is dominant, as raindrop size is comparable to the wavelength. Therefore, rainfall effects depend on wavelength. Rain attenuation coefficient may be found from Figure 4.2-4, which has been developed empirically.

   It is seen from this figure that the repeater spacing should be less than 5 km during heavy rain. Accurate geographical rainfall rates are needed. The specific rainfall rate for short periods of time are difficult to obtain. However, the estimated rainfall rate, which is shown in Figure 4.2-5, may be obtained from the cumulative distribution. Since heavy rain is considered to affect a small region for a short time, path diversity is useful to lenghten repeater spacing.

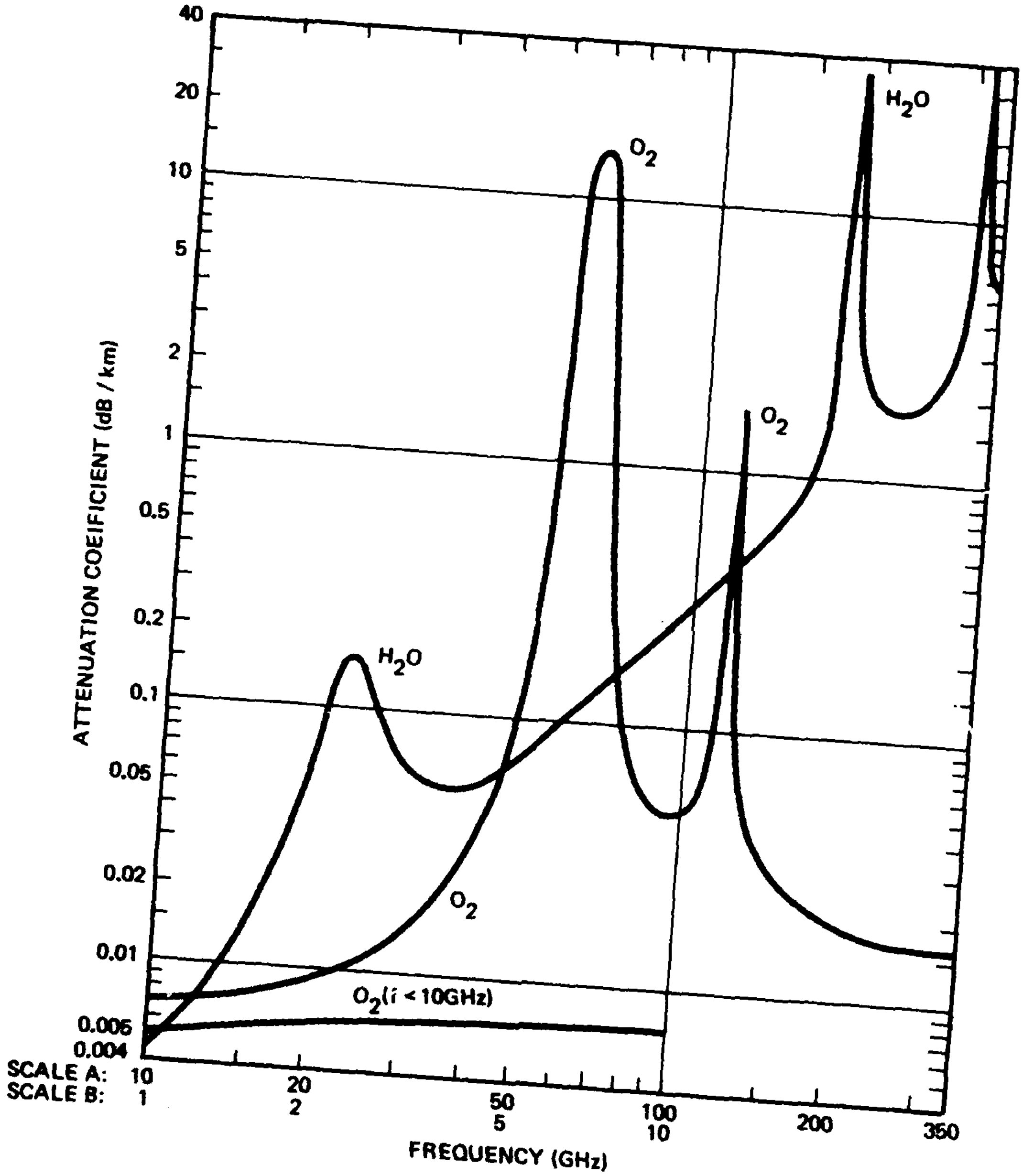


Figure 4.2-3. Specific Attenuation Coefficient for Atmospheric Gases

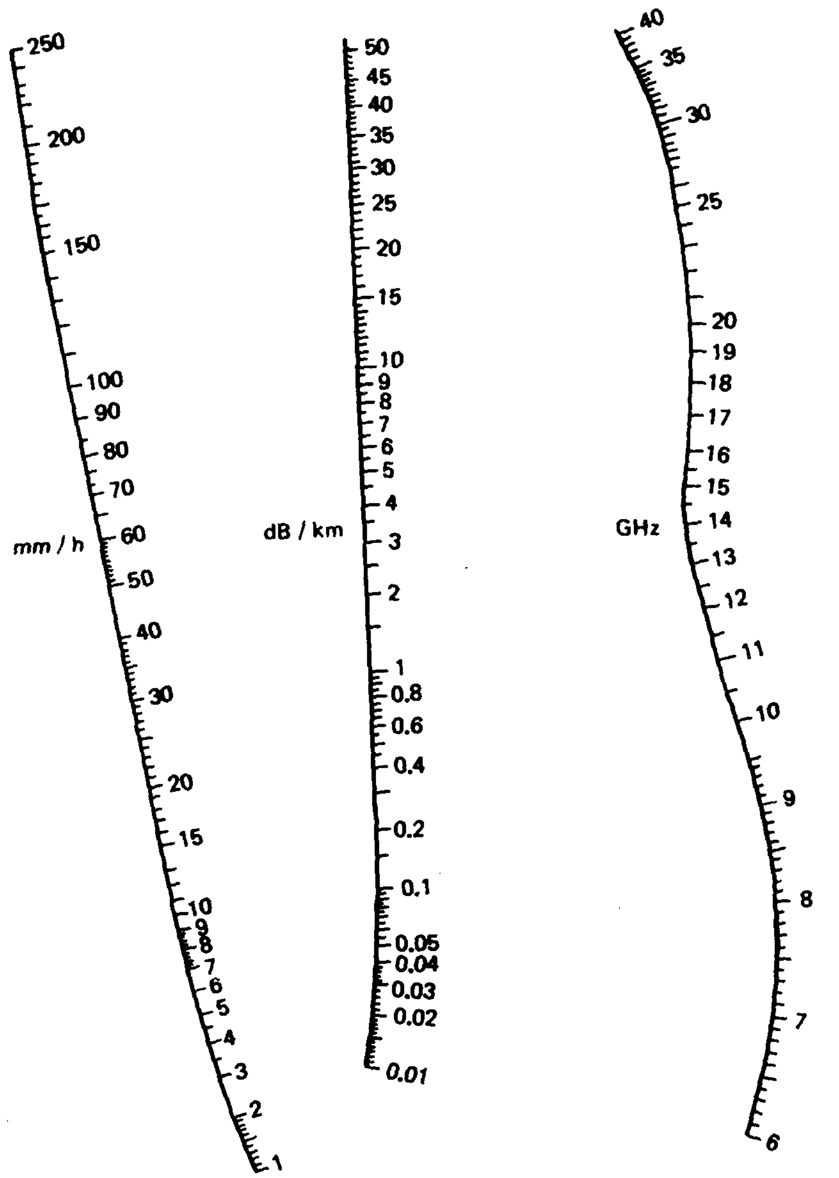


Figure 4.2-4. Rain Attenuation Coefficient Nomograph

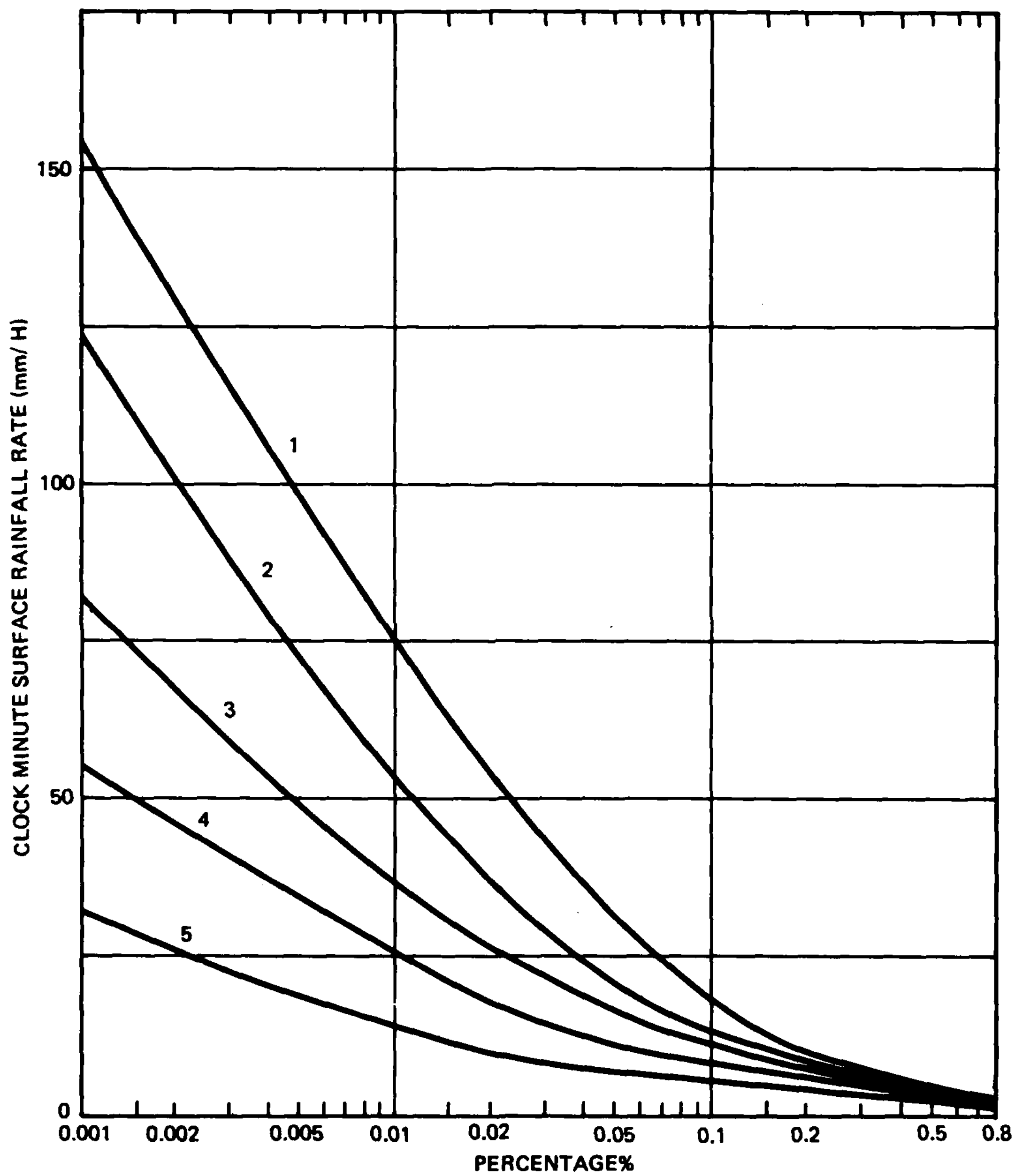


Figure 4.2-5. Percent of Average Year Rainfall Rate is Exceeded for Rain Climates

3. Other Parameters. There are several other factors affecting millimeter wave propagation. They are scintillation fading, attenuation due to snow, cloud, and fog, reflection due to ice, etc. except scintillation fading effects of these factors are small compared to rainfall effect. Hence, the system gain for millimeter wave link is given by

$$G'_s = G_s + L_r + L_o + L_s \text{ (dB)} \tag{4.2-17}$$

where

G_s = system gain as defined by Equation 4.2-15

L_r = attenuation due to rainfall

L_o = attenuation due to H_2O and O_2

L_s = scintillation fading

Figure 4.2-6 shows values of scintillation fading for 35 and 100 GHz.

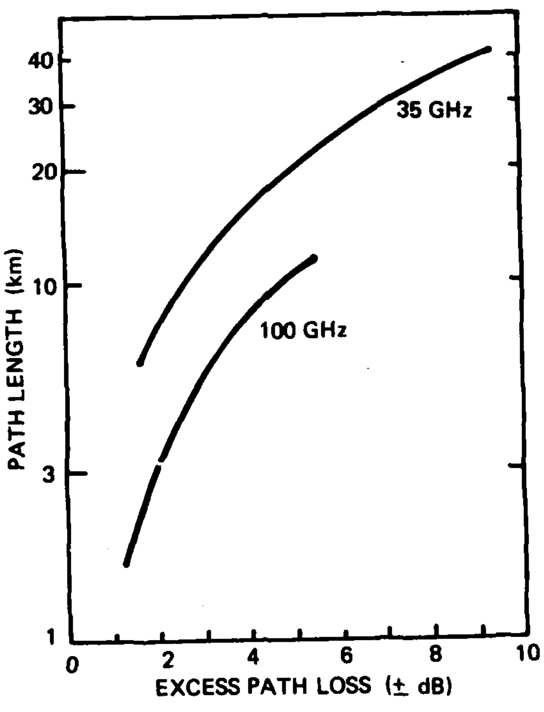


Figure 4.2-6. Scintillation Fading for 35 and 100 GHz

4.3 TROPOSPHERIC SCATTERING TRANSMISSION

In this section, performance evaluation methodology for digital troposcatter links is presented. The highest operating frequency for the troposcatter link is considered to be limited to 10 GHz because scattered microwave energy in a troposphere is reduced significantly in the higher frequencies.

4.3.1 Preliminary Considerations for Link Design. In order to make an effort to reduce path loss, the takeoff angles are made as small as possible. Negative takeoff angles are desirable if possible. Thus an elevated tropo station site and antenna height are necessary. When the takeoff angle is fixed, the median path loss varies about 0.1 dB/mi. In other words, increasing takeoff angle is equivalent to increasing path length.

As in the case of a radio link system, the fading inherent in a tropospheric system may be divided into fast and slow fading. Fast fading is caused by multipath transmission in the atmosphere, the fading rate increases proportional to the frequency or the distance and is of higher magnitude than that encountered in a radio link. Received signal level (RSL) under fast fading obeys the Rayleigh distribution. On the other hand, slow fading follows log normal distribution. Median signal levels are higher in warm, humid climates than in cold, dry climates and seasonal variations of as much as $\pm$ 10 dB or more have been observed. In troposcatter links, diversity techniques, either space or frequency, playes an important role in reducing fast fading effect although quad diversity is required for most troposcatter links, dual diversity is also useful for the limited frequency band system operating at 1 and 2 GHz bands.

4.3.2 Link Design. Determination of the long term distribution of short term SNR, γ_0, is extensively described in the NBS report (Ref. 4.3-1). To increase the time availability to troposcatter link, enough system

gain should be considered in a system design. The system gain was defined in the radio link section. Assuming that binary DPSK modulation technique is used, the probability of an outage corresponding to 10^{-4} bit error rate or worse is given by Reference 4.3-2, and 4.3-3.

$$P_o = 1 - b \sum_{R=1}^{m} \frac{\ell^{R-1}}{(R-1)!} \qquad (4.3\text{-}1)$$

where $b = (2 \times 10^{-4})$

$\ell = \ln b$

m = total diversity = 4, dual diversity
8, quad diversity

The system diversity number m is determined by the product of the ratio of the transmitted bandwidth to the channel frequency correlation bandwidth and order of explicit diversity (Ref. 4.3-4). Mean outage rate can be estimated from P_o and the results of Rice (Ref. 4.3-5).

$$n_o = 2.4\ mN\ell\ b\ \frac{1 - b \sum_{R=2}^{m} \frac{\ell^{R-1}}{(R-1)!}}{1 - b} \qquad (4.3\text{-}2)$$

Where N is the average channel fade rate in Hz, the long term average fade rate has been found empirically by Grosskopf and Fehlhaber (Ref. 4.3-6, 4.3-7).

$$N = 0.56f\ (\text{GHz}) \qquad (4.3\text{-}3)$$

The mean-time-between-fade outage (MTBFO) is expressed as $1/n_o$. The mean outage duration with respect to the error rate 10^{-4} or worse is simply given by

$$t_o = P_o/\text{MTBFO} = P_o/n_o \qquad (4.3\text{-}4)$$

Thus far, the discussion and results are limited to the average value. The probability distribution of fade relative to the mean can be determined from a narrowband Rayleigh process assumption

$$P(t) = -(2/u)I_1(2/\pi\ u^2)\ \exp(-2/\pi\ u^2) \qquad (4.3\text{-}5)$$

where $u = t/t_o$ and I_1 is the modified Bessel function of the first order.

As in the case of radio link, the MTBFO with duration $t_1 \leq t \leq t_2$ can be obtained by

$$\text{MTBFO}(t_1, t_2) = \frac{\text{MTBFO}}{P(t_2) - P(t_1)} \qquad (4.3\text{-}6)$$

The number of fade outages of given range of fade duration during a one minute call is given by

$$n = \frac{60}{\text{MTBFO}(t_1, t_2)} \qquad (4.3\text{-}7)$$

Note that the above result is based on the assumption that fade outage occurs once during one minute call; that is, range II and III in Table 4.0-1. But it is obvious that the fade outages can occur several times during one minute call under fast changing fading channel. These phenomena requirements are specified in range IV and V. The probability specifying several outages can be obtained from the mean outage rate described in (Equation 4.3-2) as:

$$\frac{2}{60} \leq n_o \leq \frac{5}{60} \qquad \text{for range IV}$$

$$\frac{5}{60} \leq n_o \qquad \text{for range V} \qquad (4.3\text{-}8)$$

The mean outage rate or number of fade outages which are related to time availability are derived from the probability, P_0, described in (4.3-1). However, the probability, P_0, is expressed in terms of random variable γ_0. It is, therefore, desirable to obtain the total probability of fade outage occurrence, which is not restricted to a particular γ_0, for the given range specified in Table 4.0-1. This can be achieved by multiplying the conditioned probability, P_0, and the probability of attaining γ_0 or worse. Since the conditioned probability is a step function of γ_0, the probability of fade outage occurrence changes rapidly for small variation of γ_0. Thus, it is a reasonable approach to select values of γ_0 corresponding to near unity of the conditioned probability for each range.

It is empirically known that the probability of γ_0 has a log-normal distribution form with standard deviation 4-8 dB.

For a reliable system design purpose, the most stringent requirements and time availabilities are chosen and listed in Table 4.3-1.

Table 4.3-1. γ_0 Requirements for Digital Troposcatter

BAND	DIVERSITY	γ_0 (dB)*	EXCEEDED ALL BUT R_0 PCT OF TIME
L,S	DUAL	12	.075
	QUAD	10	.075
C	DUAL	15	.01
	QUAD	8	.01

*Without implementation margin

To remove the modulation scheme restriction, the linear relationship between DPSK and other modulation schemes corresponding to 10^{-4} BER is needed, that is

$$\gamma_0^A = \gamma_0 + \Gamma \quad \text{(dB)} \tag{4.3-9}$$

where γ_o^A = SNR requirement of an alternate modulation scheme

γ_o = SNR requirements listed in Table 4.3-1

Γ = Ratio between 10^{-4} BER point for DPSK and the alternate modulation technique (dB)

4.3.3 System Gain

The system gain which satisfies γ_o and time availability requirements can be obtained from equation (Reference 4.3-1).

$$G_s = L_f + L_S(0.95,R) + S_t + L_w + L_m + L_p - (G_t + G_r - L_c) + L_i \qquad (4.3\text{-}10)$$

where

L_f = free space path loss

L_S (0.95,R) = scatter loss not exceeded more than (100-R) percent of time computed at a service probability of 0.95

R = time unavailability

S_t = γ_o requirement

L_w = total waveguide loss

L_m = miscellaneous loss

L_p = power loss due to signal processing at the transmitter

G_t = transmitter antenna gain

G_r = receiver antenna gain

L_c = aperture to medium coupling loss

L_i = implementation margin and power loss in amplifier = 10 dB

The parameters L_f, R, S_t, L_w, L_m, G_t, G_r are either self-explanatory or already explained in the radio link section. Other parameters are explained below.

1. Aperture to Medium Coupling Loss. Aperture-to-medium coupling loss has sometimes been called the antenna gain degradation. It occurs because of the troposphere nature. As the beam becomes more narrow due to higher gain antennas, the received signal level does not proportionally increase as it would under free-space. This difference is called the antenna-to-medium coupling loss. This loss is proportional to the scatter angle, θ, and the beamwidth, Ω. The beamwidth is obtained from the formula:

$$\Omega = \frac{240}{f \times D_r} \qquad (4.3\text{-}11)$$

where D_r = antenna reflector diameter (m)

f = carrier frequency (GHz)

The ratio θ/Ω is computed and from this ratio the aperture-to-medium coupling loss may be obtained from Table 4.3-2.

Table 4.3-2. Antenna-to-Medium Coupling Loss

Coupling Loss (dB)	Antenna Beamwidth Ratio, θ/Ω	Coupling Loss (dB)	Antenna Bandwidth Ratio, θ/Ω
0.18	0.3	2.95	1.4
0.40	0.4	3.22	1.5
0.60	0.5	3.55	1.6
0.90	0.6	3.80	1.7
1.10	0.7	4.10	1.8
1 20	0.75	4.25	1.9
1.40	0.8	4.63	2.0
1.70	0.9	4.90	2.1
1.95	1.0	5.20	2.2
2.2	1.1	5.48	2.3
2.42	1.2	5.70	2.4
2.75	1.3	6.00	2.5

2. Service Probability. Service probability is defined as a probability of obtaining a predetermined grade of service or better (10^{-4} BER or smaller in this work) during a given percentage of time (Ref. 4.3-8). This parameter is needed to measure a prediction uncertainty due to the fact the the received signal level through troposphere varies as hour, day, and season. For instance, service probability 0.95 (which is normally satisfactory allowance for errors) during 99 percent of the time, is that 95 out of 100 path would be expected to provide the specified grade of service or better during 99 percent of all hours (or a year).

4.4 EHF SATELLITE

Satellite link power budget and performance prediction have been well developed in the past decade. For system operating below 10 GHz, parameters specifying either the system or the channel are known to a degree of accuracy such that performance evaluation can be conducted deterministically with a few dB system margins to cover uncertainties. However, for satellite systems operating at a frequency above 10 GHz, the excess attenuation caused by atmosphere, rain and some other factors can no longer be handled deterministically. Statistical or probabilistic treatment is needed. This section emphasizes this aspect of EHF satellite communications.

4.4.1 Atmospheric EHF Absorption. EHF wave propagating in the atmosphere is subject to absorption caused by oxygen and water vapor, clouds, fog, snow, and sleet. These absorptions are discussed in the following subsections (Ref. 4.4-1).

4.4.1.1 Attenuation of Oxygen and Water Vapor. Propagation through the clear atmosphere at frequencies above 10 GHz is affected by molecular absorption due to oxygen and water vapor. The combined attenuation due to these two components is shown in Figure 4.4-1. This figure gives the one-way zenith attenuation values between the surface of the earth and the top of the atmosphere. The relative effects of water vapor are also shown in Figure 4.4-1. The contribution due to water vapor is for an assumed density of 7.5 gm/m^3, which is typical of a moderately humid atmosphere (43% relative humidity at 30°C). Both the 0% and 100% dashed

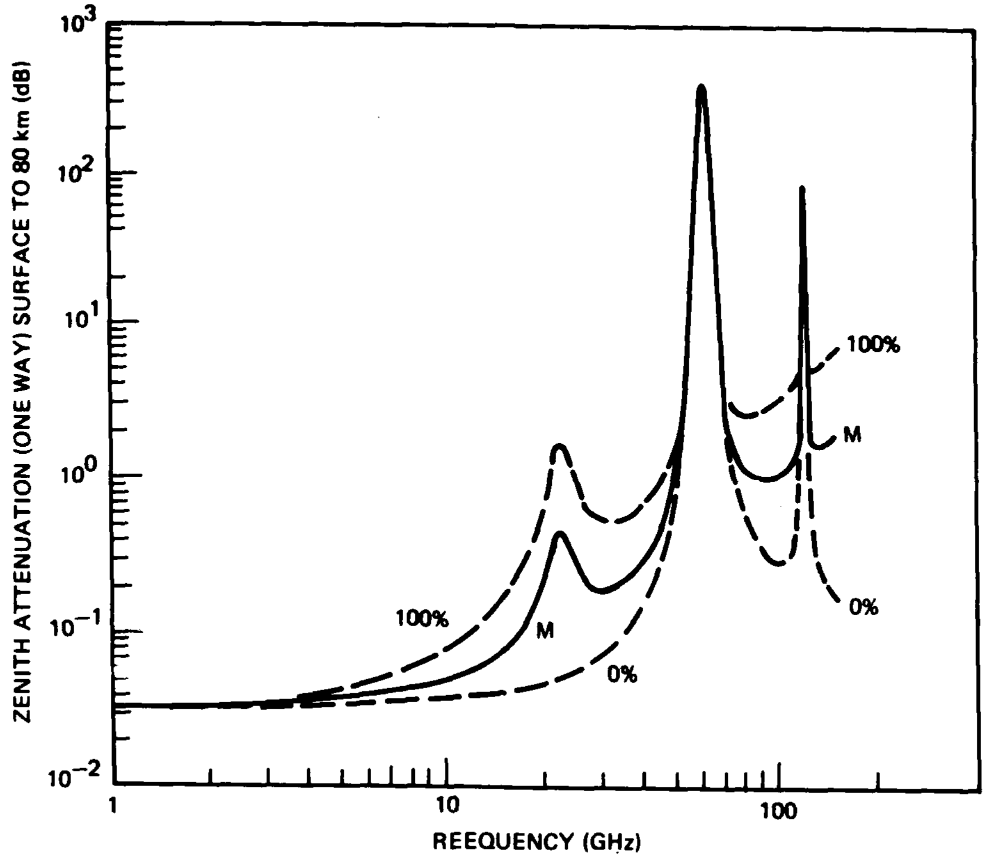


Figure 4.4-1. One-Way Zenith Attenuation Through the Atmosphere for Various Relative Humidities (M = 43% at 20°C)

curves are fictitious but serve to illustrate the bounds on water vapor absorption. Attenuation due to molecular absorption in the atmosphere is always present and must be included in the computation of total path attenuation. Assuming a flat earth, the atmospheric attenuation as a function of elevation angle is given by the zenith attenuation multiplied by the cosecant of the elevation angle. Using the zenith attenuation versus frequency curve of Figure 4.4-1 for a moderately humid atmosphere, atmospheric attenuation versus frequency and elevation angle are presented in Table 4.4-1. This table is given here for convenience. For elevation angles other than those given in the table, cosecant relationship can be used to determine the attenuation; however, for elevation less than 10 degrees, the cosecant relation is no longer valid due to earth curvature and refraction effect. It is fortunate that elevation angles of interest for Turkey are about 20 degrees.

Table 4.4-1. Atmospheric Attenuation Due To Oxygen and Water Vapor

FREQ. (GHz)	ATTENUATION (dB) ELEVATION ANGLE (deg)			
	90	30	20	10
7	0.05	0.1	0.2	0.3
20	0.25	0.5	0.8	1.4
30	0.2	0.4	0.6	1.1
40	0.3	0.6	0.9	1.7
45	0.6	1.2	1.8	3.5
50	1.8	3.6	5.3	10.4

4.4.1.2 Attenuation of Clouds and Fog. Whereas the drop sizes of rain (between 0.5 and 5 mm in diameter) make it necessary to apply the Mie scatter theory to calculate the loss, the droplet sizes in clouds and fog (between 10 and 100 mm in diameter) permit the use of the Rayleigh approximation. Consequently, it is possible to express the attenuation due to clouds and fog in terms of the total water content per unit volume. Thus the absorption within such a cloud or fog can be written as:

$$A_c = K_e M \quad \text{(dB/Km)} \tag{4.4-1}$$

where A_c = the absorption coefficient

K_e = attenuation coefficient in dB/Km $(g/m^3)^{-1}$

M = liquid water content in g/m^3

Values of K_e are plotted in Ficure 4.4-2 for the frequency range from 7 to 50 GHz and for various temperatures. Given the liquid water content and vertical extent of clouds or fog, the zenith attenuation may be determined; for other elevation angles ≥ 10°, the cosecant relationship may be applied.

Mist and fog were studied by Ride and Ryde (Ref. 4.4-1) and a relationship between mean water content and visibility was developed. For example, for heavy fog the visibility is 100 feet ant $M = 2.3 g/m^3$. The height of a fog layer is typically only 200 m, and consequently, attenuation due to fog is a potential problem only for terrestrial communication paths.

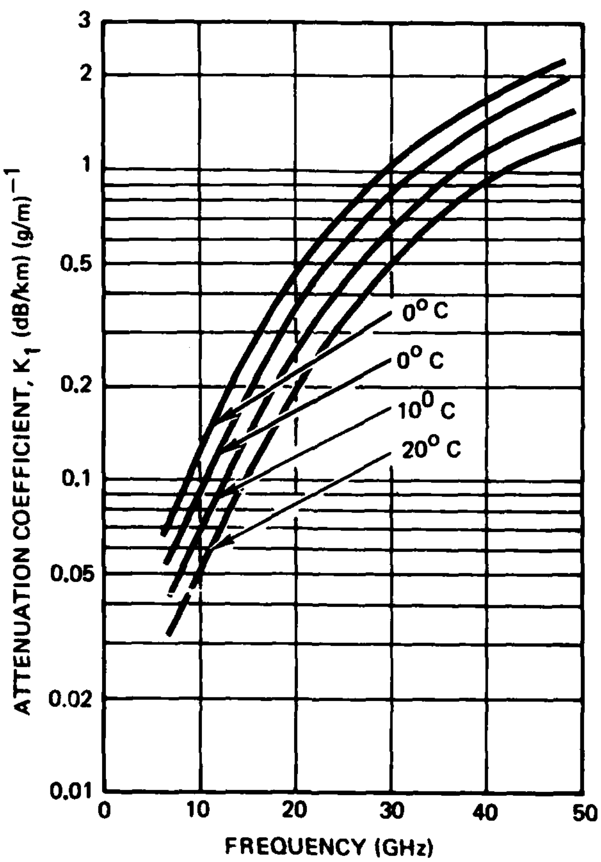


Figure 4.4-2. Attenuation by Water Clouds or Fog at Various Temperatures as a Function of Frequency

Clouds will be characterized into three types: liquid-water, fair weather and ice clouds. Liquid water clouds may have liquid-water content of 1 to 2 g/m^3 and a vertical extent of 6 km which would extrapolate to zenith attenuation values in excess of 10 dB at frequencies above 30 GHz. However, the presence of liquid-water clouds such as steady rain and thunderstorm implies a rain environment and are accounted for in the rain attenuation model. Fair weather cumulus clouds have a liquid water content of 0.2 gm/m^3 and extent of 1 Km corresponding to zenith attenuation of 0.1 to 0.5 dB from 20 to 50 GHz. The increase in path attenuation due to fair weather clouds must be added to the attenuation due to atmospheric absorption. Ice clouds, due to the difference in dielectric properties, give attenuation about two orders of magnitude smaller than water clouds of the same water content and may be ignored.

4.4.1.3 Attenuation of Snow and Sleet. Attenutation by dry snow and sleet is generally negligible due to the relatively low dielectric constant of water in the solid phase. Attenuation by wet sleet and melting snow is appreciable but has not been investigated because of its relative rarity, at least at ground level. Melting snow is present in the melting layer at the top of rain region (liquid water drops) but its contribution is small due to the relatively short path lengths through the melting region.

4.4.1.4 Atmospheric Attenuation Effects. A space-earth communications link is subject to attenuation due to oxygen, water vapor, fog, clouds, and snow. A model is required to determine the attenuation from each of these components. These meteorological parameters must have statistical data accumulated over a sufficient period of time in order to make a reasonable estimate of probability of future occurrence. However, for present purposes, the following conclusions are drawn for attenuation prediction for fog, clouds, snow and other propagation effects of EHF waves in the troposphere and ionosphere (Ref. 4.4-2, 4.4-3, 4.4-4).

1. When water is frozen, as in the case of particles in many clouds, the property of refractive index of water no longer applies and the corresponding loss resonance appears at much longer wavelengths. The net result is that ice and dry snow exhibit very low loss in the microwave band, and therefore the attenuation of clouds is neglected.

2. Fog is comprised of small drops of liquid; but the density of liquid water in a heavy fog is less than one-twentieth that of a heavy rain so the attenuation encountered is very small and is neglected also.

3. Another propagation effect, very familiar to those concerned with terrestrial radio-relay systems, is signal fading caused by layers and other aberrations of the refractivity profile of the troposphere. These attenuations of the signal occur on microwave beams that are essentially horizontal, thereby interacting at near-grazing angles with the layers. But for typical earth-satellite paths at elevation angles of more than a few degrees, this type of fading is not troublesome and will not be discussed in detail, nor will the relatively small scintillations that are also created by non-uniform refractivity.

Consequently, except the attenuation of oxygen and water, other minor effects are omitted for EHF link performance prediction.

4.4.2 Statistical Rain Attenuation. To predict attenuation due to rain, one needs the statistical data of rain, satellite path, and attenuation prediction. They are discussed in the following paragraphs.

4.4.2.1 Globe Rain Model. The estimation of rain attenuation on a global basis is by necessity a statistical process. The constituent parameters of predictive models which must be based on statistical averages include:

1. Rain rate versus probability of occurrence, which is a spatial and temporal average of available statistics for given geographic regions.

2. Vertical extent of the rain which has a latitude, seasonal and rain rate dependence.

3. Raindrop shape and size distribution which is dependent on rain rate and temperature.

4. Rain rate distribution along the propagation path.

The effect of applying these statistical processes to global predictions is to incur large uncertainty bounds on the resulting estimates. To realize the most representative rain attenuation estimates it is then necessary to utilize the most accurate rain statistics and attenuation prediction mode.

In 1974, CCIR proposed (Ref. 4.4-1) a globe rain model which divides the world into five regions. For each region a cumulative rain rate distribution function is given. This CCIR model represented the best data available when it was developed. Since that time, the model has been revised as countries determined that the model did not accurately represent their region. The discrepancies arise from the fact that the observed rain rates in these areas are factors of two and three larger than those predicted by the CCIR rain rate distribution.

Recently, Crane has introduced an interesting and perhaps most accurate model for estimating rainfall attenuation along an earth-satellite path, and he has proposed a set of eight regions into which the earth is separated for purposes of estimating rainfall rates (Ref. 4.4-5). This new model is consistent with the latest climatological data, i.e., annual precipitation data, number of thunderstorm days, latitude, general topography, and data on the ground circulation of the atmosphere. This model incorporates the rain rate distributions for regions which include administrations who have formally amended the CCIR model and those administrations who did not formally recommend changes to the model. In addition, the new model more accurately represents observed rain rate distributions for the tropical regions. Figure 4.4-3 presents the eight rain rate climate regions. The rain rate distribution functions for each region are presented in Figure 4.4-4. Table 4.4-2 presents the data contained in Figure 4.4-4 in another format which is easy and convenient to use for certain types of prediction.

The rain climate regions were defined so that the rain rate distributions for adjacent regions bound the possible variation of the distribution for a region, either in time (at a point) or in space (within the region). The distributions of the adjacent regions can then be used to provide bounds on the rain attenuation estimates for a given region due to the point-to-point and year-to-year variations from the observed annual distribution function.

Figure 4.4-4 and Table 4.4-2 were used for Turkey EHF satellite performance evaluation. It is noted that Turkey is located in climate region D.

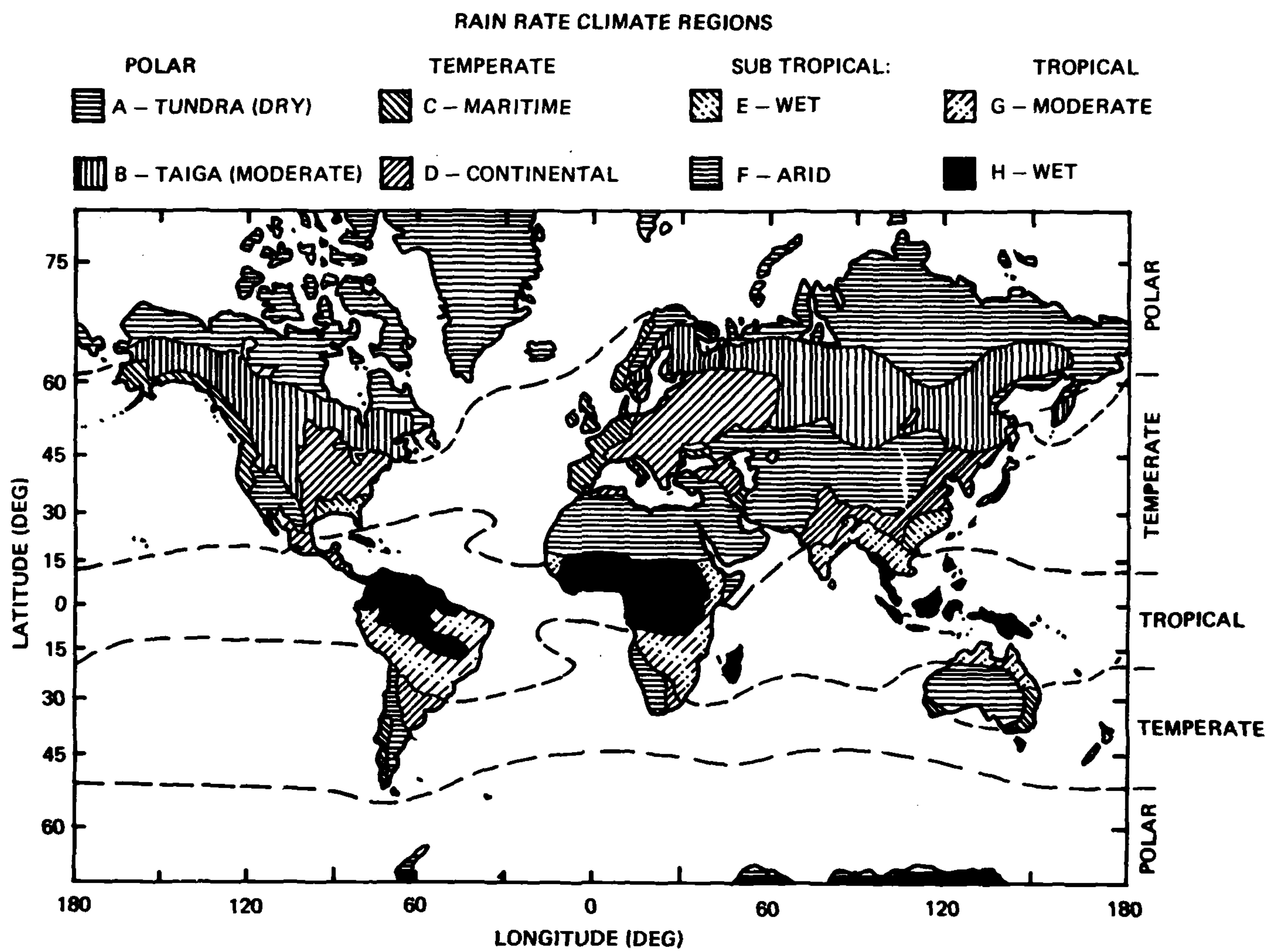


Figure 4.4-3. Global Rain Rate Climate Regions

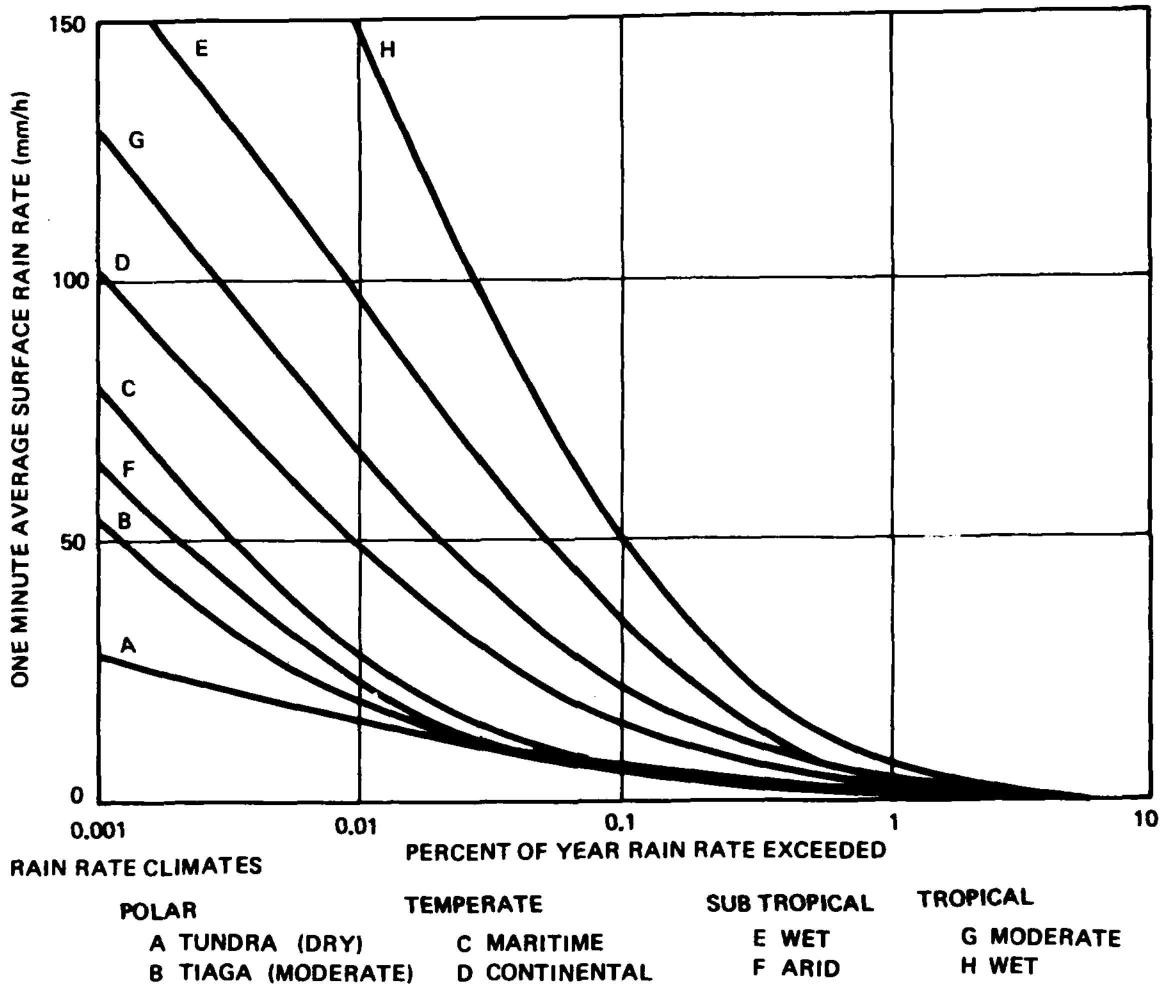


Figure 4.4-4. Rain Rate Distributions

Table 4.4-2. Rain Rate Distribution Values (MM/H)

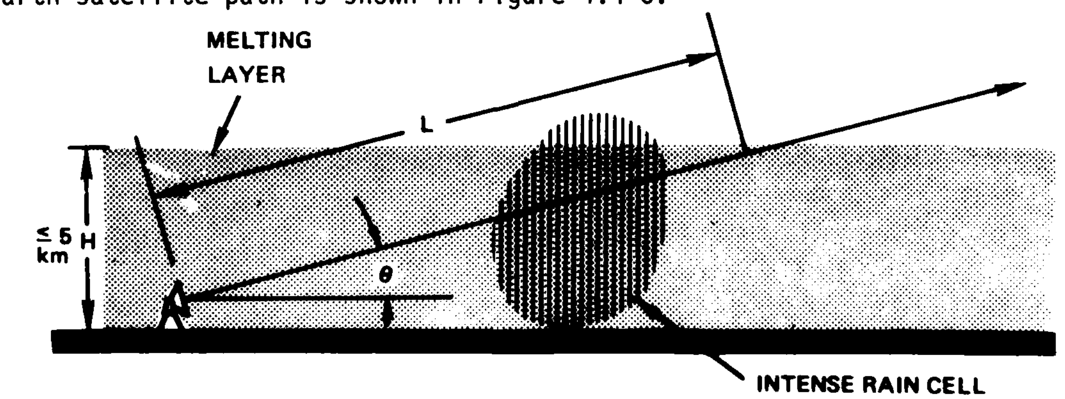
PERCENT OF YEAR	RAIN RATE CLIMATE REGIONS							
	A	B	C	D	E	F	G	H
0.001	28	54	80	102	164	66	129	251
0.002	24	40	62	86	144	51	109	220
0.005	19	26	41	64	117	34	85	178
0.01	15	19	28	49	98	23	67	147
0.02	12	14	18	35	77	14	51	115
0.05	8.0	9.5	11	22	52	8.0	33	77
0.1	5.5	6.8	7.2	15	35	5.5	22	51
0.2	4.0	4.8	4.8	9.5	21	3.8	14	31
0.5	2.5	3.0	2.8	5.2	8.5	2.4	7.0	13
1.0	1.7	1.8	1.9	3.0	4.0	1.7	4.0	6.4
2.0	1.1	1.4	1.0	1.8	2.0	1.1	1.6	2.8

4.4.2.2 Propagation Path Length. It is generally assumed that the rain rate is uniform from the surface to the melting layer where rapid conversion from water to ice occurs. Ths specific attenuation is then assumed to be constant up to the height of the melting layer end zero above. There is some uncertainty associated with the height of the melting layer. Specific values are available for locations where weather radar data has been collected and typical results indicate that for all regions, 5 km is the proper height for melting layer estimation.

To determine the propagation path, the simplest models assume a cosecant path length dependence, i.e., path length

$$L = H \csc \theta$$

where H is the height of the top of the rain layer and θ is the elevation angle of the path as shown in Figure 4.4-5. This model is only valid for $\theta \geq 10°$. Inherent in the cosecant model is the assumption that the path average rain rate is equal to the surface point rain rate, i.e., that the rain rate is horizontally homogeneous. This canonic model of the earth-satellite path is shown in Figure 4.4-5.



GENERAL ASSUMPTION:

RAIN RATE UNIFORM FROM SURFACE TO MELTING LAYER HEIGHT (0^{o}C isotherm), H, AND VANISHES FOR HIGHER ALTITUDES

COSECANT MODEL:

ASSUMES RAIN HORIZONTALLY HOMOGENEOUS

L = H COSECANT (θ), θ ≥ 10^{o}

EMPIRICAL MODELS:

OBSERVATIONS (attenuation and weather radar) SHOW INHOMOGENEOUS RAIN DISTRIBUTION ALONG PATH LEADING TO EMPIRICAL PATH AVERAGE FACTORS

Figure 4.4-5. Canonic Model of Earth-Satellite Path

In contrast to this model, meteorological data shows that the path average rain rate exceeded for a specified percentage of time may differ significantly from the point rain rate exceeded for the same percentage of time. This inhomogeneous rain rate distribution along the path is evident in rain attenuation observations and has led to the concept of an effective path length. This path length factor is typically derived from measured rain attenuation by assuming constant specific attenuation along the path and that the ratio of measured rain attenuation, A_m, to calculated rain attenuation, a_c, equals the ratio of effective path length to physical path length, i.e., path length factor

$$P_f = A_m/A_c$$

It has been observed that the variation in the empirically-determined path length factors for a given elevation angle, e.g., by a factor of two for elevation angles less than 60° and by a factor of three for elevation angles less than 20°, the variations in effective path length as determined from measured rain attenuation are due to the limited data base and to the dependence on the specific parameters of the experiments. This effective path length factor is included in the rain attenuation presented in the next subsection.

4.4.2.3 <u>Rain Attenuation</u>. The excess attenuation due to rain for satellite link path is predicted by (Ref. 4.4-6)

$$A = H \csc\theta\, \alpha(f)\, \gamma(D)\, R^{\beta(f)-\delta(D)}$$

where

H = height of the melting layer (0°C isotherm)

θ = elevation angle

$\alpha(f)$, $\beta(f)$ = frequency dependent coefficients used to estimate specific attenuation for a given rain rate

R = point rainfall rate (mm/h) exceeded P percent of time

$\gamma(D)$, $\delta(D)$ = multiplier and exponent for effective path length

D = $H \cot(\theta)$ surface projection of the propagation path

Height of the 0°C isotherm depends upon latitude and season, and 5 km is considered a nominal value of the height. This value is derived from zonally averaged temperature data and for all weather conditions. As rain does not occur uniformly during the year but has marked seasonal dependence, the 0°C isotherm height models have been appropriately weighted. The coefficients of the specific attenuation $\alpha(F)$ and $\beta(F)$ are displayed in Figures 4.4-6 and 4.4-7. The multiplier, $\gamma(D)$, and exponent, $\delta(D)$, of the effective path length are shown in Figures 4.4-8 and 4.4.9, respectively.

4.4.3 Required Link Margin. Link margin required to protect a satellite path such that the path has a specified time availability can be calculated by using the methodology developed in the last subsection for the specified rain climate region, elevation angle, and frequency. Table 4.4-3 shows an example of the results for regions D and H and 20° elevation angle.

Furthermore, to provide worst case atmospheric attenuation due to oxygen and water vapor, the corresponding value shown in Table 4.4-1 should be added to the value given in Table 4.4-3.

4.4.4 Time Availability. The time availability as seen by an end-to-end user depends on two factors; namely, channel or path availability and system availability. The system availability can be further broken down to component availabilities. For a satellite system, the time availability is given by

$$A = A_t A_u A_s A_d A_r$$

where A = time availability of a satellite link

A_t, A_s, A_r = time availabilities of ground transmitting terminal, satellite, and ground receiving terminal, respectively

A_u, A_d = time availabilities of uplink and downlink, respectively

For the satellite it will be assumed that the use of highly reliable components, redundant subsystems and an on-orbit spare assure its operation, i.e., A_s=1.

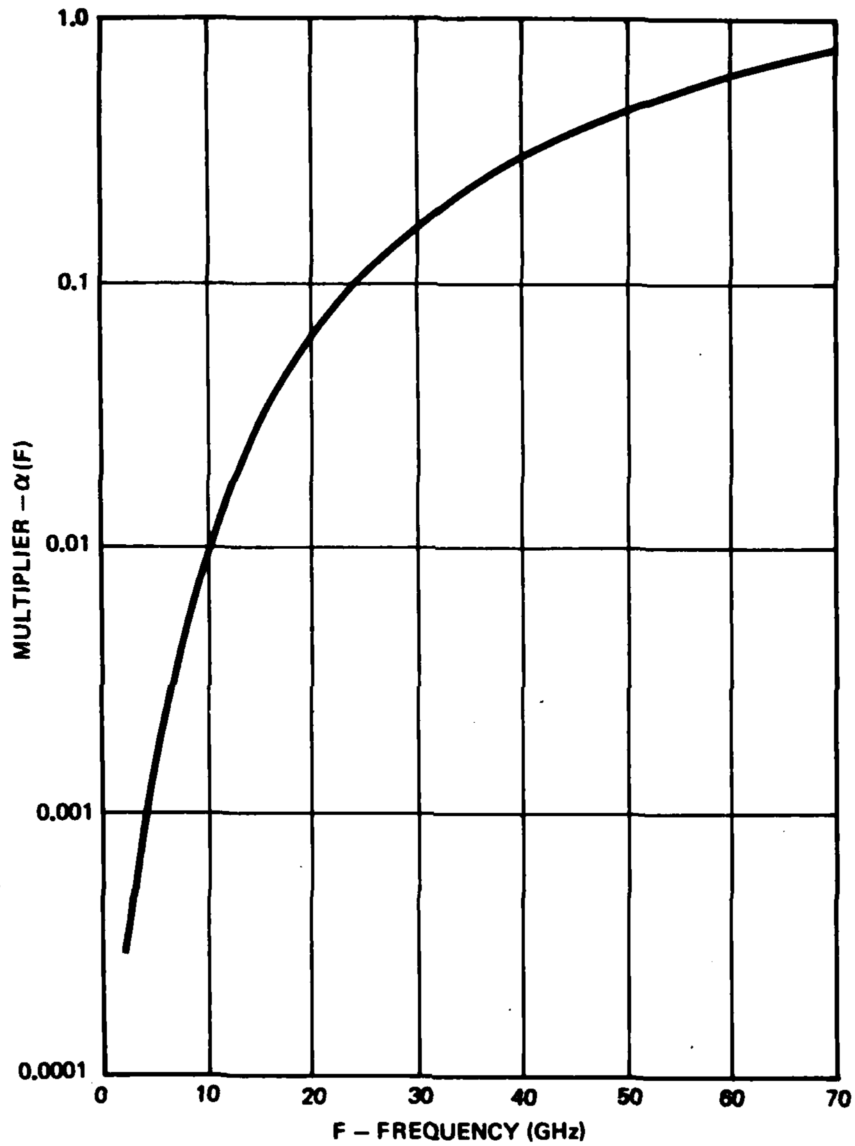


Figure 4.4-6. Multiplier in Specific Attenuation Model, α(F)

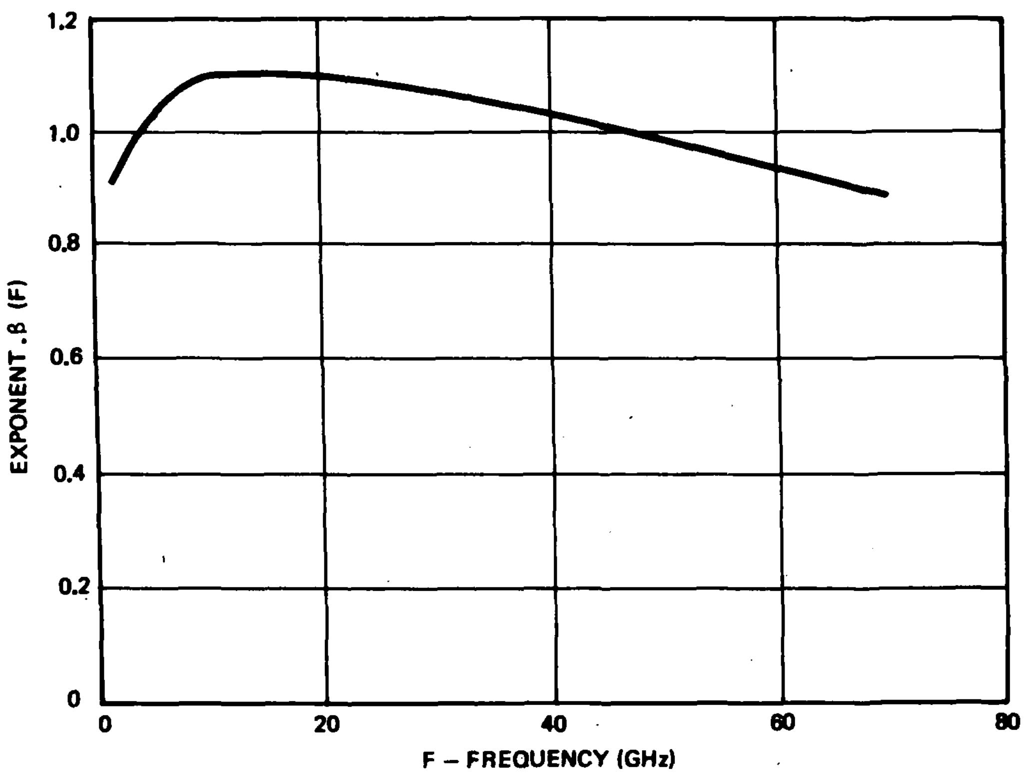


Figure 4.4-7. Exponent in Specific Attenuation Model, β(F)

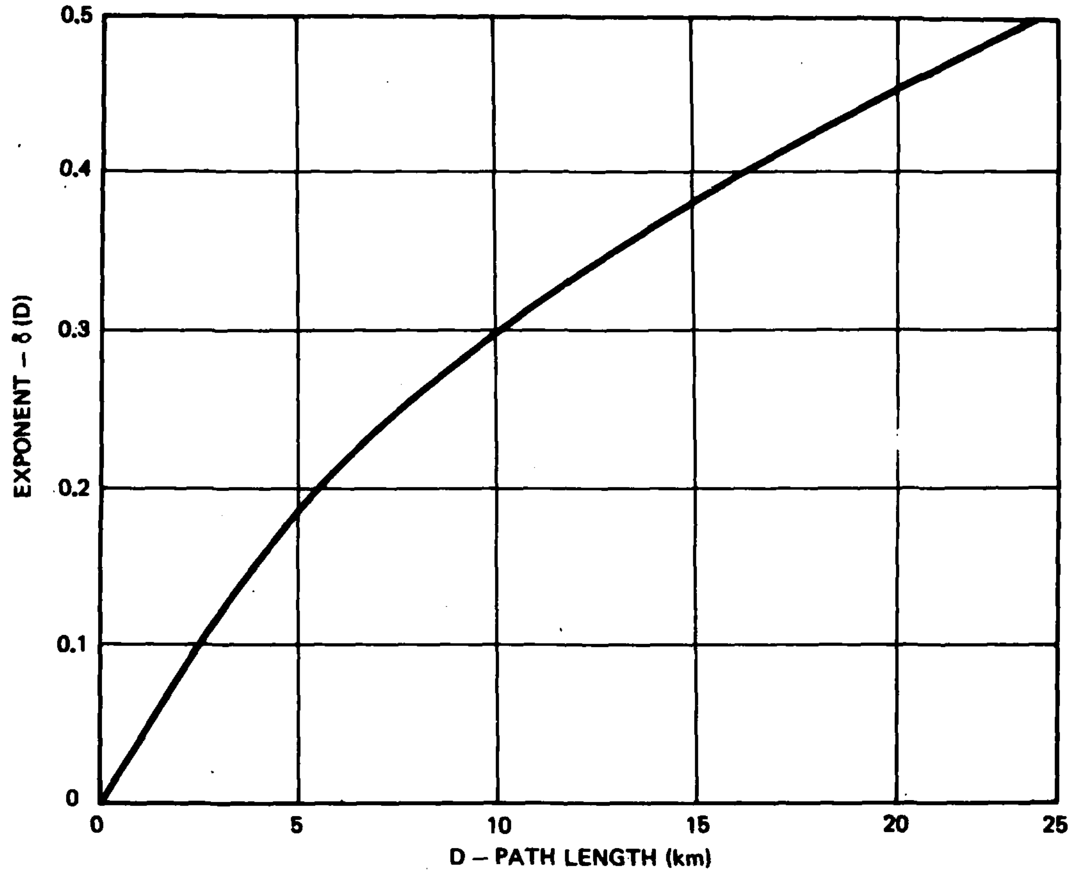


Figure 4.4-8. Exponent in Path Average Model, δ(D)

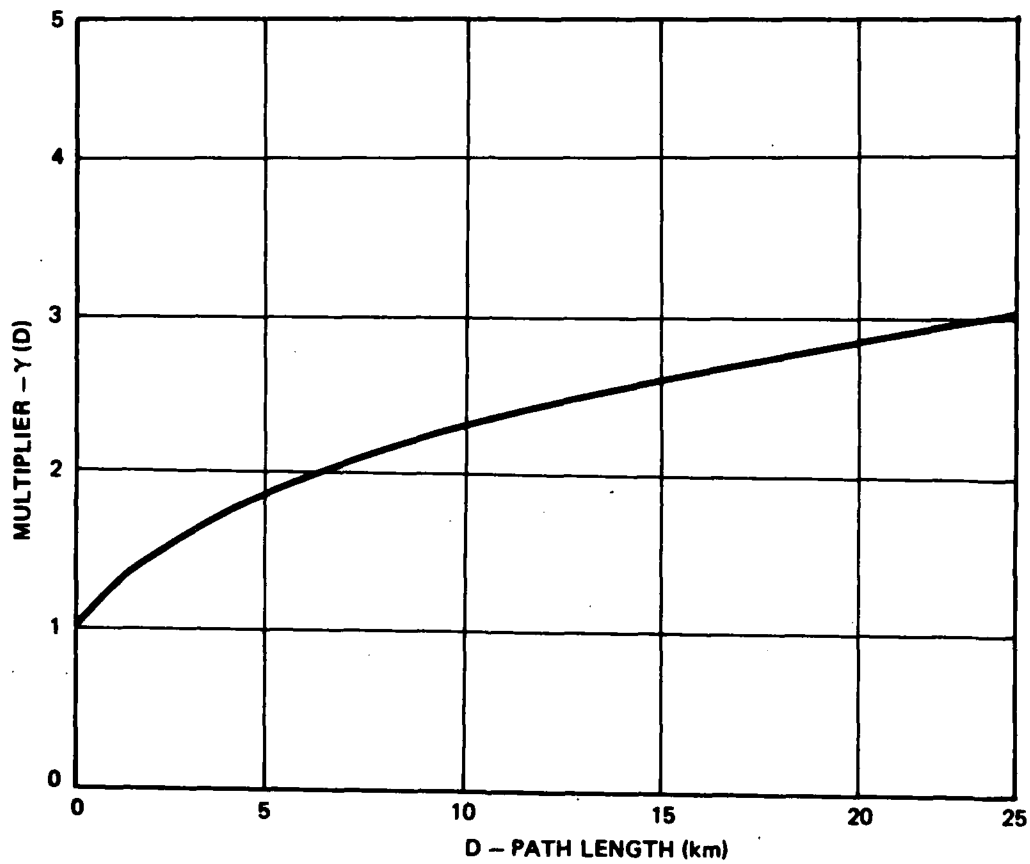


Figure 4.4-9. Multiplier in Path Average Model, $\gamma(D)$

Table 4.4-3. Required Path Margins Due to Atmospheric and Rain Attenuation (20° Elevation Angle)

REQUIRED PATH AVAILABILITY (%)	REQUIRED PATH MARGIN (dB)									
	CLIMATE REGION D(1)					CLIMATE REGION H(2)				
	FREQUENCY (GHz)					FREQUENCY (GHz)				
	20	30	40	45	50	20	30	40	45	50
97	2	5	8	11	16	4	9	16	20	27
98	3	6	10	14	19	6	13	22	27	35
99	4	9	15	19	25	10	23	38	46	56
99.5	6	13	22	28	35	16	37	60	73	84
99.7	8	18	29	35	43	24	55	86	102	115
99.8	9	21	35	42	51	31	70	109	128	142
99.9	13	30	48	58	68	45	100	152	177	193

(1) Climate Region D: Moderate Rain Rate (Large Areas of Europe and Eastern Conus)

(2) Climate Region H: Highest Rain Rate (Tropics)

The terminal availability may be expressed as

$$A = \frac{MTBF}{MTBF+MTTR}$$

where

$$MTBF = \text{mean-time-between-failure}$$

$$MTTR = \text{mean-time-to-repair}$$

The MTBF of the terminal components is of course a tradeoff between cost and reliability.

The MTTR is dependent on the supply of replacement parts and the accessibility of the equipment, and varies significantly with the type of terminal. For the present study, it is assumed that the terminal availability is identical for transmitting and receiving, i.e.,

$$A_t = A_r$$

As regards the path availability, the uplink EIRP (Equivalent Isotropic Radiated Power) and the concomitant path availability may be driven by considerations of jamming threats and may be higher than the downlink path availability. Alternatively, the down link path availability requirement may be more stringent that the uplink if loss of the downlink signal would incur unacceptable delays due to reacquisition of a pseudo-noise code sequence. Due to the hypothetical nature of the system design and performance evaluation of the DCS III investigation, the uplink and downlink path availabilities are assumed to be equal, that is

$$A_u = A_d$$

Under these assumptions, the time availability can be expressed as

$$A = A_p^{\,2} A_g^{\,2}$$

where

$$A_p = A_u = A_d = \text{path availability}$$

$$A_g = A_t = A_r = \text{terminal availability}$$

The above equation is plotted in Figure 4.4-10. If it is assumed that $A_p = A_g$, the rapid increase in their required availability with increasing

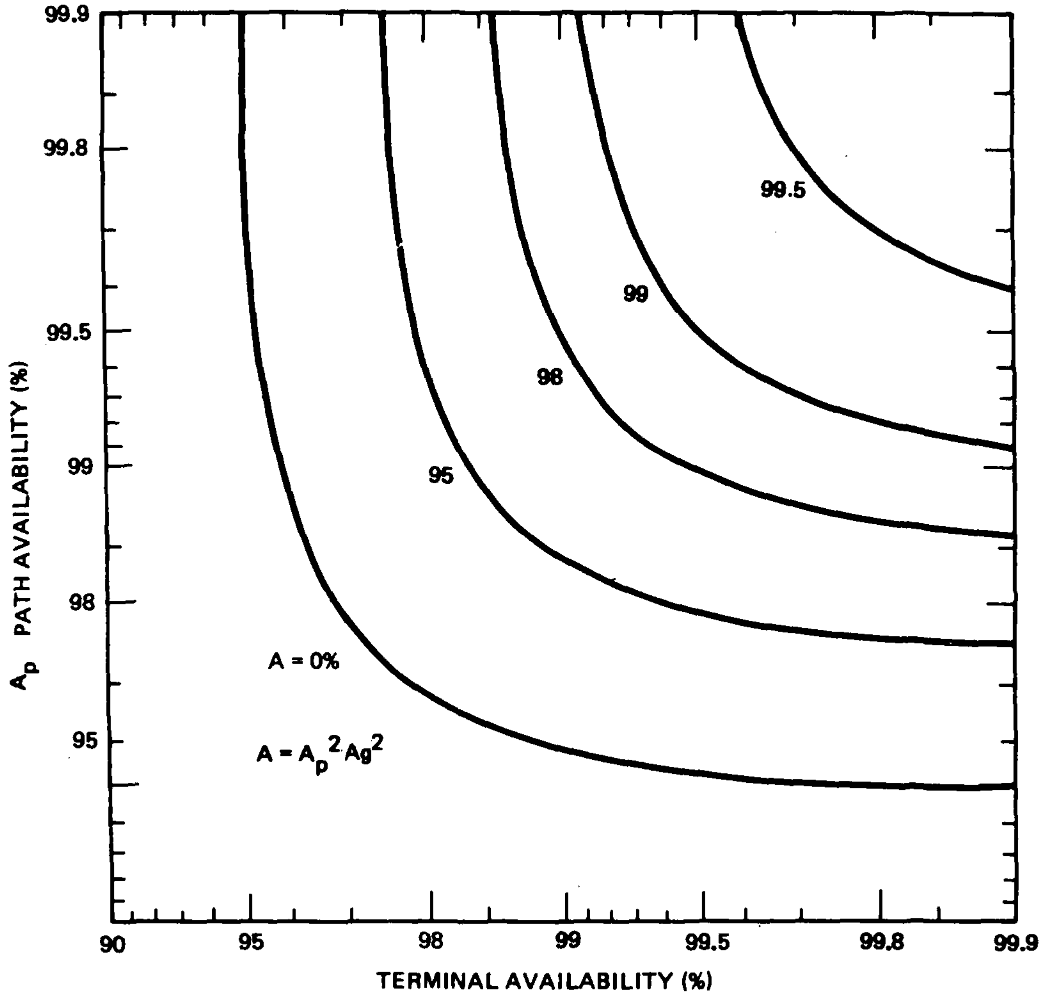


Figure 4.4-10. A_g Required Path Versus Terminal Availability With System Availability as a Parameter

time availability is evident, e.g., for $A = 90\%$, $A_g = A_p = 97.4\%$. Note also that increasing A_g or A_p beyond this balanced condition incurs an extreme increase in the availability requirement of A_g or A_p for a modest increase in time availability. In the limit, if A_g or A_p is assumed to be unity, the system percentage outage is reduced by a factor of two from the balanced case. The point being made is that to a first order the terminal availability determines the system availability, if the corresponding path availability margin is achievable. Increases in time availability beyond this point must be weighed against the cost of increasing A_g or A_p. As regards the latter, increasing the downlink path availability for mobile terminals would require increasing the terminal antenna size with concomitant increases in the required tracking accuracy, radome, weight and cost. Increasing the uplink path availability for mobile terminals will require increasing the antenna size and/or the transmitter power. For the fixed terminals, site diversity may be a viable alternative, however, site diversity will not be discussed for the present investigation.

Table 4.4-4 presents required path availability as a function of time availability with terminal availability as a parameter. Time availabilities of 95%, 99% and 99.9% are taken as the nominal requirements for this computation. Note that, in order to achieve high time availability, both the terminal availability and the path availability must be high. The required path margin as a function of path availability with frequency and climate region as parameters for an assumed elevation angle of 20° has been shown in Table 4.4-3. Note the rapid increase in required path margin for path availabilities 99%.

Note that discussion of time availability in terms of both path availability (channel availability) and terminal availability (system availability) is meaningful only when both path (channel) and terminal (system) availabilities are compatible. For most communications systems, it is usually the case that one of the two is more critical and the other can be neglected or assumed to be met.

Table 4.4-4. Required Path Availability Versus Terminal Availability

TIME AVAILABILITY (%)	TERMINAL AVAILABILITY (%)				
	95	98	99	99.9	99.99
90	99.9	96.8	95.8	95.0	94.9
95	SEE (1)	99.5	98.4	97.6	97.5
97			99.5	98.6	98.5
99				99.6	99.5
99.9					99.96

(1) Increased Terminal Availability Required, i.e., $A_t \geq 1$

4.5 OPTICAL FIBER COMMUNICATION SYSTEM

Currently, optical fiber communications technology exists as required for both the Hawaii and Germany buried cable systems. Optical fiber links of five or more kilometers and operating up to DS-3 (47 Mbps) are commonplace. Major telecommunications suppliers, such as Western Electric, GTE-Lenkurt and NEC, have announced production equipment included for DS-3 transmission between central office exchanges with repeater spacing varying from 5 to 10 kilometers depending on required bandwidth and other factors.

Because fiber optics technology is currently at an early point on the maturation curve, however, major advances by the year 2000 will have impact on this projected DCS III alternative. Current transmitters and receivers, and their associated circuitry are being produced in relatively small quantities, and are implemented with discrete components particularly in the analog portions. Well before the year 2000, integration of these units will occur. Multiple emitters (e.g., injection-diode lasters) and detectors (e.g., avalanche photodiodes) will be available in monolithic packages. Initial development work to this end is already known to be underway in Bell Laboratories, GTE, NEC, Philips Research Labs and Siemens. The net result will be a decrease in size and cost, and an increase in reliability. For example, the projected MTBF of a link is 200,000 hours.

Operating parameters foreseen for the future are based on current advanced work. Present-day fiber optic systems operate in the region of 850 nm wavelength, largely determined by the characteristics of early emitters. It is now well known that fiber losses and material dispersion are much lower when operated at wavelengths in the vicinity of 1.3 microns. At that wavelength, repeaterless transmission has already been demonstrated at 45 Mpbs over a span of 55 Km. Such performance will be standard by the year 2000.

In the system design, fibers having a loss of 1 dB/km at 1.3 microns has been used. Splices will be made at 1.5 km intervals, and will contribute a loss of 0.5 dB each. Since many parameters needed for system performance prediction are not definitely known at this time, no system performance

computation will be made for the optical fibers option of buried cable systems prepared for both Hawaii and Germany. However, the methodology of system design based on required performance is outlined below. The emphasis is placed on high rate digital data and digital voice transmission.

The system design and/or performance prediction of a user specified LED vs. LD for light source, PIN vs. APD for photodetector, fibers, repeaters, modulators and encoders, signal format, multiplexers and demultiplexers. The two major parameters which would have to be determined are optical power and response time. Factors which must be considered for these two parameters are the following:

- Required BER and SNR to maintain signal and message integrity
- Nominal power radiated by a light source, the peak power available, the expected intensity degradation and the life time
- Coupling loss between the light source and optical fiber, between fiber to receiving component
- Required light power for properly operating the photodetector
- Other losses such as coupling, splicing, repeaters, signal-splitters and degradation caused by temperature variations.

The optical power requirement can be easily computed by following the step-by-step procedures as listed in Table 4.5-1. Most of the items listed in the table are self-explanatory except the following. The expected splice and connector losses depending on fiber types; for fixed splice, the loss is 0.3 and 0.5 dB for step, and graded-index fiber respectively, for demountable connector, the loss is 1.0 and 1.4 dB. Allowance should be made for temperature variations depending upon the temperature range, either within the range of 10 to 30°C or not, and whether temperature compensation circuitry is used or not. The loss allowance is 4, 2, 1, and 0 dB for the various combinations of temperature range and compensation circuitry. The component degradation allowance shown in the table is for component performance deterioration with time depending upon the light source and photodetector. Losses of 2, 3, 4, and 5 dB are allocated for the source-detector combinations of LED and PIN, LED and APD, LD and PIN, and LD and APD respectively.

Table 4.5-1. Optical Power Requirements

PARAMETERS	VALUE
Required Bandwidth	______ MHz
or data rate	______ Mbps
Required SNR	______ dB
Signal Format	
Terminal or Repeater Spacing	______ km
Optical Fiber Attenuation	______ dB/km
Average Power Output of Light Source	______ dBm
Power Degradation at end of Line	______ dB
Total Available Power	______ dBm
Detector Required Optical Power	______ dBm
Total Fiber Loss	______ dB
Source Coupling Loss	______ dB
Detector Coupling Loss	______ dB
Splice Loss	______ dB
Temperature Variation Allowance	______ dB
Component Degradation Allowance	______ dB
Connector Losses	______ dB
Total Attenuation Losses	______ dB
Total Power Margin	______ dB
Excess Power	______ db

The rise time is very important for a high rate digital optic fiber system because both light source and photodetector have their own rise time, furthermore, the dispersion of optical fiber impacts the pulse rise time and, hence, limits either the bit rate or repeater spacing. The total allowable system rise time in nsec is equal to 0.35 divided by bit rate in terms of Gbps for a not-return-to-zero signal. The rise time calculation is displayed in Table 4.5.2. The system rise time is the root square sum of the component rise times. In general, the purpose of this computation is to check whether the system rise time is smaller than the total allowable system rise time. If not, some other fast-response light source and/or photodetector or fiber would have to be used.

Table 4.5-2. Optical Fiber Digital Link Rise Time Computation

PARAMETER	VALUES
Total Allowable Rise Time (0.7/bit rate in Gbps)	________ nsec
Light Source Rise Rime	________ nsec
Photodetector Rise Time	________ nsec
Total Fiber Dispersion	________ nsec
System Rise Time	________ nsec

The rise time calculation shown above is very easy, however, the fiber rise time due to dispersion is difficult to estimate by calculation. The measured dispersion characteristic should be used if it is available. When the link distance is large enough to require repeaters then the design calculations of light source power and rise time become an iterative procedure. A simpler design approach is available if a regenerative repeater is used. In this approach, the whole link is divided into a number of identical sections, and a typical repeater section is designed with appropriately allocated BER as the design goal.

4.6 AIRBORNE RELAY PLATFORM

This section presents the performance evaluation methods for the airborne relay platform. There are four different types of airborne relay platforms which can be employed for the purpose of communications relay: manned aircraft, unmanned aircraft, tethered balloon, and high altitude powered platform (HAPP). But all four systems are common in the sense that they can be regarded as low altitude stationary satellite systems. The only difference is their altitude; the tethered balloon keeps 4.5 km, and the others keep about 20 km. Therefore, the same performance evaluation methodology can be applied to all of them with the consideration of different altitudes.

4.6.1 System Gain

The system gain for the algebraic difference between the transmitter power and the received signal strength for the bit error probability of 10^{-6} is given by

$$G_s = L_s + F + L_w + L_m + L_r - G_t - G_r \quad \text{(dB)} \qquad (4.6\text{-}1)$$

Where L_s = free space path loss
= $92.5 + 20 \log f \text{ (GH}_z) + 20 \log D \text{ (Km)}$

F = fade margin

L_w = total waveguide loss

L_m = miscellaneous losses due to waveguide aging, receiver figure aging, coupling loss, etc. = 6 dB

L_r = attenuation due to rainfall

G_t, G_r = transmitter and antenna gain

The parameters L_s, L_w, L_r, G_t, and G_r are already explained in the radio link section. In the airborne relay link, the fade margin F is considered to be less 8 dB and it is mainly caused by atmospheric migration or absorption. The detailed rainfall attenuation and other negligible atmospheric effects are well-described either in the radio link or satellite link section.

In order to obtain the transmitter power which can provide enough signal to noise ratio to the receiver input to meet the BER requirement, the relationship between the system gain and transmitter power is expressed

$$G_s = P_t - P_n - E_b/N_o - N_F \qquad \text{(dB)} \qquad (4.6\text{-}2)$$

where P_t = transmitter output power

P_n = 10 log kTB = receiver input power

E_b/N_o = bit signal to noise ratio for BER requirement

N_F = receiver noise figure

4.6.2 Unavailability

Since the operating frequencies for the airborne relay link are suggested at 7 and 8 GHz, the rainfall attenuation is expected to be small, and the aircraft trouble and equipment failure are considered to cause major contribution to the unavailability. The flight test record of the L-450 engine which was suggested for use for the airborne relay platform shows that the in-flight shutdown rate is 1 per 100,000 hours operating time and that the altitude of 15 km can be achieved within two hours. From these data, the unavailability due to the aircraft is about 3×10^{-5} of a year including one hour of unexpected preparation time to take off. The reliability record for the tethered balloon is not available. It is assumed that the reliability of tethered balloon is the same as the aircraft.

Including other effects such as ground/on-board equipment failure, storm, etc. the unavailability per one airborne link might be set to be less than 1×10^{-4}.

5.0 COMPARATIVE PERFORMANCE EVALUATION OF ALTERNATIVE TRANSMISSION SYSTEMS

Candidate DCS III transmission alternatives for the three interest areas have been briefly described in Section 2.3. Methodologies needed to evaluate performances of these systems have been developed and documented in Section 4. This section presents application of the corresponding developed methodology to the system under consideration and results so obtained for each transmission system.

It should be noted that because of the following factors:

- Transmission alternative designs are done only to specify the highest level system parameters due to uncertainties of technology development.
- Transmission media involved are at different stage of maturity
- The system designs were performed under the condition that requirement data supplied are limited to number of voice channels between pairs of communications nodes. No traffic statistics is available.

Therefore, the accuracy and depth of treatment for different systems are not compatible at all. However, every possible measure has been taken to ensure that the end results and their comparison are meaningful to the extent practically possible.

5.1 SYSTEM PERFORMANCES OF HAWAII TRANSMISSION ALTERNATIVES

The system performance of Hawaii transmission alternatives, H-1, and H-2 were evaluated. Their results are provided in the following two subsections.

5.1.1 System Performance of Transmission Alternative H-1. As prescribed in Section 2.3.1, millimeter wave radio link is proposed as one of the alternative systems for Oahu Island in Hawaii. Two operating frequencies, 15 and 35 GHz, can be chosen for the radio link to avoid the heavy attenuation due to water vapor and oxygen gas illustrated in Figure 4.2-3. However, the frequency 38 GHz is considered as an appropriate frequency due to increasing communications rate.

In order to find the optimum system parameters for Oahu Island, the fade margin which satisfies the fade outage rate requirement (media unavailability) will be obtained, and the system gain will be obtained by using the fade margin. Finally, each system parameters such as antenna gain, transmitter power output, repeater spacing distance will be found.

From equation (4.2-13) the range III fade outage rate n which requires the most stringent fade margin may be found by substituting t_1=5 and t_2=60, and the probability P_0 that the received signal level is below threshold. Where the probability P_0 is obtained from equation (4.2-1) with the appropriate parameters that can be found from the Phase IA Report and the system descriptions.

The average annual temperature, t, for Oahu Island is known as 76.3°F from the U. S. Weather Report. The percentage of fading season, a, is summarized from equation (4.2-4):

$$a = \frac{(t/50)\ 8 \times 10^6 \text{sec}}{3.1536 \times 10^7 \text{sec}} = 0.39 \qquad (5.1\text{-}1)$$

The climate and terrain factor, c, is set to 1. The diversity combiner hysteresis ratio r^2 is set to normal value 2.51 from the common system description. The longest repeater spacing distance, D, is suggested at 6.5 Km with consideration of the heavy attenuation due to rainfall. The two antenna separation, S, in the case of space diversity reception, is set to 5 m, which is equivalent to 55 MHz separation obtained by equation (4.2-5) in the case of frequency diversity reception. Now the probability P_0 can be obtained from equation (4.2-1) with the known parameters in metric unit.

$$P_0 = \left(r^2 + \frac{1}{r^2}\right) \frac{ac\ D^4}{4047\ s^2}\ 10^{-F/5}$$

$$= \left(2.51 + \frac{1}{2.51}\right) \frac{0.39 \times 1 \times (6.5)^4}{4047\ (5)^2}\ 10^{-F/5} \qquad (5.1\text{-}2)$$

$$= 0.02 \times 10^{-F/5}$$

The average fade duration time, t_o, is needed to evaluate the fade outage rate, and t_o can be found from equation (4.2-7):

$$
\begin{aligned}
t_o &= 0.141\ g(D)^{1/2}\ 10^{-F/20} \\
&= 0.141 \times 200(6.5)^{1/2}\ 10^{-F/20} \qquad (5.1\text{-}3) \\
&= 72 \times 10^{-F/20}
\end{aligned}
$$

The fade outage rate n for range III which requires the most stringent fade margin, is obtained from equation (4.2-13) with the substitution of $t_1 = 5$, $t_2 = 60$, and P_o.

$$
n = \frac{60\ P_o \left[e^{-1.15\left(\frac{t_1}{t_o}\right)^{2/3}} - e^{-1.15\left(\frac{t_2}{t_o}\right)^{2/3}} \right]}{t_o}
$$

$$
= \frac{60 \times 0.02 \times 10^{-F/5} \left[e^{-1.15\left(\frac{5}{72 \times 10^{-F/20}}\right)^{2/3}} - e^{-1.15\left(\frac{60}{72 \times 10^{-F/20}}\right)^{2/3}} \right]}{72 \times 10^{-F/20}} \qquad (5.1\text{-}4)
$$

It should be decided that the optimum fade outage rate for 5 Km distance of repeater spacing in Oahu Island. According to the general definition of DCA end-to-end requirement shown in Table 4-1, the range III fade outage rate and unavailability for 600 mile circuits are assigned to 2.5×10^{-4} and 1×10^{-4} respectively. However, the design of DCS III is limited to each area or country. Therefore, the fade outage rate and unavailability for 6.5 Km distance of circuit are allocated to 2.5×10^{-4} and 1×10^{-4}, respectively. In order to meet the fade outage rate requirement, the 11 dB fade margin is found from equation (5.1-4).

For the detailed system parameters specification, the system gain is required to be found from equation (4.2-17). The free space loss is given by:

$$\begin{aligned} L_S &= 92.5 + 20 \log f + 20 \log D \\ &= 92.5 + 20 \log 35 + 20 \log 6.5 \\ &= 139.6 \text{ dB} \end{aligned} \qquad (5.1\text{-}5)$$

The total wave guide loss L_w for the transmitter and receiver is set to 2 dB and the miscellaneous loss L_m is known as 6 dB. The scintillation loss L_s and water vapor attenuation L_o for 6.5 Km distance of 35 GHz operation are obtained as 2 dB and 1 dB respectively. The biggest climate effect, rainfall attenuation can be obtained from the Figure 4.2-4 and 4.2-5. In Figure 4.2-5, Hawaii belongs to curve 1. With the assumption that two-third of unavailability, $2/3 \times 10^{-4}$ is caused by rainfall, 25 mm/h of rainfall rate is found from curve 1 in Figure 4.2-5. The rainfall attenuation coefficient for 25 mm/h and 35 GHz can be found from Figure 4.2-4. The rainfall attenuation for 6.5 Km is

$$L_r = 6.5 \text{ D dB/Km} = 42.3 \text{ dB}$$

The antenna gain for the transmitter and receiver is set to 46 dB which can be achieved by 0.6 m diameter of reflector type antenna.

The system gain for 35 GHz operating frequency and 6.5 Km repeater spacing given by

$$\begin{aligned} G_s &= L_s + F + L_w + L_m + L_r + L_s + L_o - G_t - G_r \\ &= 105.9 \quad \text{dB} \end{aligned} \qquad (5.1\text{-}6)$$

Since the system gain is defined as the power difference between the transmitter and the minimum received power to achieve the BER requirement, it can be represented as follows:

$$G_s = P_t - P_n - N_f - E_b/N_o$$

where P_t = transmitter power

P_n = received noise power

N_f = receiver noise figure

E_b/N_o = signal to noise ratio corresponding to BER = 10^{-4}

The received noise power P_n with the bandwidth B = 15 MHz is given by

$$P_n = 10 \log k\ TB = 10 \log (1.38 \times 10^{-23}) (300°K) (25 \text{ MHz})$$

$$= -129.8 \quad \text{dB} \qquad (5.1\text{-}7)$$

The receiver noise figure N_f at 35 GHz is known to 7 dB (the receiver noise figure can be absorbed into the noise temperature T), and the signal to noise ratio corresponding to 10^{-4} BER is 9 dB. Thus, the required transmitter power becomes

$$P_t = G_s + P_n + N_f + E_b/N_o \qquad \text{(dB)}$$

$$= 106.9 - 129.8 + 7 + 9 = -6.9 \quad \text{dB (205 mW)} \qquad (5.1\text{-}8)$$

Hence 2 watt (3 dB) transmitter output power is enough for the achievement of BER = 10^{-4} requirement.

As a result, the proposed values for Oahu Island radio link are listed in Table 5.1-1.

5.1.2 System Performance of Transmission Alternative H-2. A coaxial cable system is proposed for Oahu Island. The system performance is evaluated in the following photographs. Overall system performance is specified as an error rate of 10^{-6} and time availability is 99.9 percent for a two-way coaxial cable link. The methodology to evaluate the two basic requirements of the coaxial cable system has been developed in Section 4.1.

5.1.2.1 Bit Error Rate Evaluation of a Postulated Link. A cable link with cable length of 100 kilometers and DS 3 data rate of 44.736 Mbps is used as a postulated link for the analysis. The cable transmission line is shown in Figure 5.1-1.

Table 5.1-1. Proposed System Parameters for Oahu Island Millimeter Wave Link

Parameter	Value
Frequency	35 GHz
Repeater Distance	6.5 km
Transmitter Power	2 Watt
TX Antenna Gain	46 dB (0.6 m diameter)
RX Antenna Gain	46 dB (0.6 m diameter)
BER	$< 10^{-4}$
Space Diversity*	5 m vertical separation of two antennas
Frequency Diversity*	55 MHz frequency separation
Information Bandwidth	25 MHz
Unavailability	$< 1 \times 10^{-3}$

*Either space or frequency diversity reception.

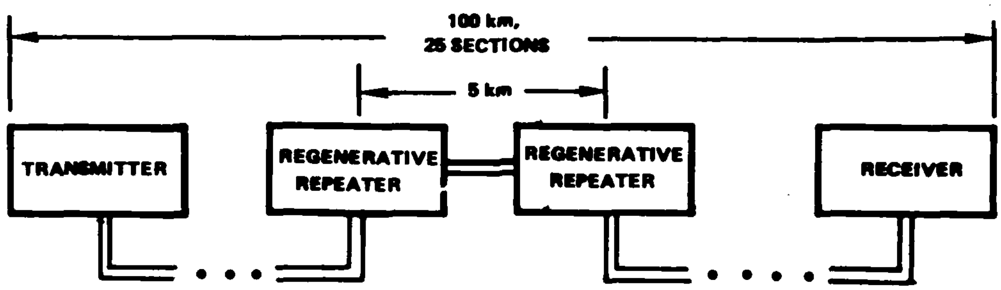


Figure 5.1-1. Postulated Cable Model for Hawaii

Regenerative repeaters are used at regularly spaced (4 kilometers) intervals along the transmission line to reconstruct the digital signal, thereby eliminating the effects of accumulated noise and distortion. The system parameters are listed in Table 5.1-2. First of all the link calculation between repeater and repeater (or transceiver) is shown in Table 5.1-3 (Ref. 5.1-1, 5.1-2).

Table 5.1-2. System Parameters

System Capacity	Information Transmission Rate	Line: 44.736 Mbps
	Capacity	Voice: 672 Channel/Cable
Line Equipment Design	Transmission Medium	2.6/9.5 mm Coaxial Cable
	Transmission Line Code	Tenary Code, m = 3
	Maximum Link Length	100 km
	Repeater Spacing	4 km
	Repeater Error Rate	10^{-8}/Repeater
	Line Loss	14.6 db/km @ 40 MHz
	Total Error Rate	Less than 10^{-6}/100 km

Table 5.1-3. Coaxial Cable Link Calculation with Path Length 4 Kilometers

Parameter	Value	Comments
Tx Power (dBW)	-10 dBW	100 mW
Transmitter Coupling Loss (dB)	-0.5 dB	
Attenuation Loss (dB)	-58.7 dB	Attenuation is 14.6 dB/kW @ 40 MHz, see Table 4.1-2
Thermal Noise Power (dBW)	+127.4 dB	T = 290 K, B = 45 MHz K = 1.379×10^{-23} W/Hz
S/N Ratio (dB) $\frac{S}{N_0}$	+58.2 dB	
Amplitude & Time Degradation (dB)	-9.5 dB	From Figure 4.1-9 Eye Degradation Contours
Equalizer Loss (dB)	-12 dB	NF of equalizer-amplifier
Cross Talk (dB)	-2.0 dB	
Receiver Coupling Loss (dB)	-0.5 dB	
Available S/N Ratio (dB)	+34.2 dB	
Required S/N Ratio (dB)	-21 dB	For tenary code m = 3, it requires S/N = 21 dB At BER = 10^{-8}, see Figure 4.1-4
Margin (dB)	13.2 dB	

Twenty-five tandem links (each 4 kilometers in length) are necessary to construct a cable link 100 kilometers in length. The bit error rate for twenty-five tandem links is approximately given by

$$P = 25 P_e = .25 \times 10^{-6} \qquad (5.1\text{-}9)$$

where P is the BER of the postulated link and is the worst case BER of any cable link in Oahu Island, and P_e is the BER of each 4 kilometers cable link.

From the above analysis, we conclude that the proposed cable system can meet the BER requirement with 10^{-6}.

5.1.1.2 Time Availability. In setting the system time availability objective (99.9%), the effects of cable damage and effects of failures from all other sources are treated separately. The major contribution to total unavailability is expected to be cable damage and electronic failure.

A 100 km 6-tube-pair-cable (2.6/9.5 mm) is used as the reference model for the analysis. The objective for maximum service outage is less than 8.76 hours per year for a 100 km reference link or a time availability of 99.9%.

Table 5.1-4, which is a prediction based on the history (Ref. 4.1-2) of other compatible coaxial cable systems, provides a simplified breakdown of the cable outage parameters. Against each failure cause is shown the incident per year, the average tube lost, the mean down time, and service outage per year, all normalized to a 100 km 6-tube-pair-cable reference model. The equation to compute service outage due to cable damage is expressed by:

$$S_0 = I \times (T_L - S) \times T$$

where S_0 = Service outage in hr/year

I = Incidents per year

T_L = Average tube lost

S = Spare tubes, 1 spare tube pair is assumed

T = Mean down time

Table 5.1-4. Cable Outage of 100 km Model

	Failure Cause	Incidents per Year	Average Tube Lost	Mean Down Time (hr)	Service Outage (hr/year)
Cable Damage	Telephone Co. Activity	0.023	4	5.8	0.40
Cable Damage	Foreign Workman	0.060	4	6.7	1.21
Cable Damage	Lightning	0.015	3	13.0	0.39
Cable Damage	Miscellaneous	0.008	3	9.0	0.14
Electronic Failure	Multiplex	-	-	-	0.42
Electronic Failure	Line Terminal Equipment	-	-	-	0.37
Electronic Failure	Line Equipment (e.g. repeater)	-	-	-	0.41
Electronic Failure	Miscellaneous	-	-	-	0.24
Total Service Outage					3.58

From Table 5.1-4, the total service outage is 3.58 hr/year or the time availability is 99.96 percent. The parameters shown in Table 5.1-4 are based on the current coaxial cable systems. By the year 2000, the reliability of coaxial cable and electronic equipment will have great improvement without paying additional cost. It is concluded that the proposed system can meet the time availability requirement with 99.9 percent.

5.2 SYSTEM PERFORMANCE OF GERMANY TRANSMISSION ALTERNATIVES

The transmission alternatives proposed for central West Germany are an airborne relay system, designated G-1, and a buried cable system, designated G-2. Performance of these two systems was evaluated and is presented in this section.

5.2.1 System Performance of Transmission Alternative G-1.

The airborne relay platform is proposed as one of alternative systems for Central Germany. There are two different types of airborne relay platforms which can be employed in Central Germany; one is high altitude (15 km) small aircraft, the other is relatively low altitude (4.5 km) tethered balloon. Since line-of-sight (LOS) distance is proportional to the height of the site, the LOS of aircraft and tethered balloon can be extended to the distance of 400 km and 200 km, respectively. It shows that one relay platform which is either the aircraft or the balloon can provide enough ground coverage for Central Germany with a size of 120 x 100 km^2.

The two systems are basically the same; i.e., low altitude, stationary satellite systems. Hence, the performance evaluation methodology will deal with two systems together, and the difference between the two systems will be denoted, if necessary.

5.2.1.1 Error Bit Rate Evaluation.

The carrier frequencies for up and downlink are decided as 7 and 8 GHz, respectively, with the consideration of long distance of communications compared to the LOS radio link and small size of ground terminal antenna. The modulated information bandwidth is decided as 65 MHz with TDMA operation, which can provide enough information rate without taking long queueing time because the highest point-to-point channel requirement for Central Germany is 25 Mb/s. In the future, the

information rate might be increased through the reflection of increasing communication trends; however, the required channel capacity can also be reduced by the modulation technique improvement. The longest distance between the ground terminal and the relay platform is 70 km, and the lowest elevation angle of the ground terminal antenna is 10^{o} for the aircraft and 3.7^{o} for the tethered balloon.

In order to evaluate the system performance, that is, the unavailability and bit error rate, the system gain will be determined. The free space path loss for 70 km distances of 7 GHz uplink and 8 GHz downlink are given by

$$\begin{aligned} L_s &= 92.5 + 20 \log f + 20 \log D \\ &= 146.3 \text{ dB; uplink} \\ &= 147.5 \text{ dB; downlink} \end{aligned}$$

The total waveguide loss, L_w, for the transmitter and receiver is assumed to be 1 dB, and the miscellaneous loss L_m was set at 6 dB. It is known that 5 dB fade margin is enough for the satellite link which is equivalent to a higher altitude airborne link.

The rainfall attenuation, L_r, may be found from the rainfall rate and unavailability requirement. With the assumption that one-fourth of unavailabilty is caused by media, that is, rainfall, and that the remaining unavailability is caused by the equipment failure and engine trouble in the case of airborne link, 25 mm/hr of rainfall rate is induced from the curve 3 corresponding to Germany in Figure 4.2-5. It is known that the rain is formed at 5 km above sea level. Hence, one-third of the path length, that is, 70 km/3 ≈ 25 km in Central Germany is affected by rainfall in the ariborne link with 15 km altitude aircraft, and the entire 70 km length can be affected by rainfall in the tethered balloon link with 4.5 km altitude. But weather record shows the heavy rainfall is concentrated on small regions. Therefore 25 km can be considered as enough length for both cases to evaluate the rainfall effect. The rainfall attenuations for 25 km distance and 7 and 8 GHz frequency are found from Figure 4.2-4.

$$L_r = 0.2 \times D/\text{km} = 0.2 \times 25 = 5.0 \text{ dB; 7 GHz}$$

$$L_r = 0.3 \times D/\text{km} = 0.3 \times 25 = 7.5 \text{ dB; 8 GHz}$$

It is difficult to assume that the aircraft or the balloon playing a role as a relay platform can keep the same altitude all the time because of unexpected air pocket phenomena or strong wind. Therefore, the relatively wide beamwidth antennas are recommended for up and downlink. The diameter d = 0.6 m of antennas for ground-site produce the gain G and the beamwidth Φ as follows:

$$G = 0.6\left(\frac{\pi}{3}\right)^2 \left(\frac{df}{10^8}\right)^2 = 31 \text{ dB; } 7 \text{ GHz}$$
$$= 32 \text{ dB; } 8 \text{ GHz}$$

$$\Phi = (1.9)^2 \left(\frac{10^8}{df}\right) = 4.9^o; \; 7 \text{ GHz}$$
$$= 4.3^o; \; 8 \text{ GHz}$$

The on-board antenna gain is set to be 3 dB regarding the wide range coverage requirement.

The system gain defined in Section 4.7 is given by

$$G_s = L_s + F + L_w + L_r - G_t - G_r$$

$$G_s = 127.3 \text{ dB; } 7 \text{ GHz}$$

$$G_s = 130 \text{ dB; } \quad 8 \text{ GHz}$$

The transmitter output power may be obtained from equation (4.7-2). The received noise power with the information bandwidth B = 65 MHz is given by

$$P_n = 10 \log kTB = 10 \log (1.38 \times 10^{-23}) (300^oK) (65 \text{ MHz})$$
$$= -125.8 \text{ dB}$$

The receiver noise figure N_F and the required signal to noise ratio (E_b/N_o) for BER = 10^{-6} are given by

$$N_F = 5 \text{ dB}$$

$$E_b/N_o = 11 \text{ dB}$$

Then the transmitter power P_t is obtained by

$$P_t = G_s + P_n + N_F + E_b/N_o$$

$$P_t = 17.5 \text{ dB; } 7 \text{ GHz}$$

$$P_t = 20.2 \text{ dB; } 8 \text{ GHz}$$

Hence, 150 watt (21.7 dB) transmitter power is enough to achieve the 10^{-6} BER requirement.

5.2.1.2 Time Availability. In Central Germany, one airborne relay platform is used. As prescribed in Section 4.7, airborne relay platform performance evaluation methodology, the unavailability due to one aircraft is less than 1×10^{-4}, and the unavailability due to rainfall is less than 2×10^{-4} of a year. The reliability record for the tethered balloon is not available. It is assumed that the reliability of tethered balloon is the same as the aircraft. Thus, total unavailability is expected to be less than 1×10^{-3}, including equipment failure.

The system parameters proposed for the airborne relay link of Central Germany are listed in Table 5.2-1.

5.2.2 System Performance of Transmission Alternative G-2. The system performance is evaluated in this subsection. Overall system performance is specified as an error rate of 10^{-6} error/bit and time availability is 99.9 percent for a two-way coaxial cable link. The methodology to evaluate the two basic requirements of the coaxial cable system has been developed in Section 4.1.

5.2.2.1 Bit Error Rate Evaluation of a Postulated Link. A cable link with cable length of 200 kilometers and DS3 data rate of 44.736 Mbps is used as a postulated link for the analysis. The cable transmission line is shown in Figure 5.2-1.

Table 5.2-1. Proposed System Parameters for Central Germany Airborne Relay Link

System Parameter	Uplink	Downlink
Frequency	7 GHz	8 GHz
Transmitter Power	21.7 dB (150 Watt)	21.7 dB (150 Watt)
Transmitter Antenna Gain	31 dB (0.6 m)	3 dB
Receiver Antenna Gain	3 dB	32 dB (0.6 m)
BER	10^{-6}	10^{-6}
Information Bandwidth	65 MHz	65 MHz
Unavailability	10^{-3}	10^{-3}

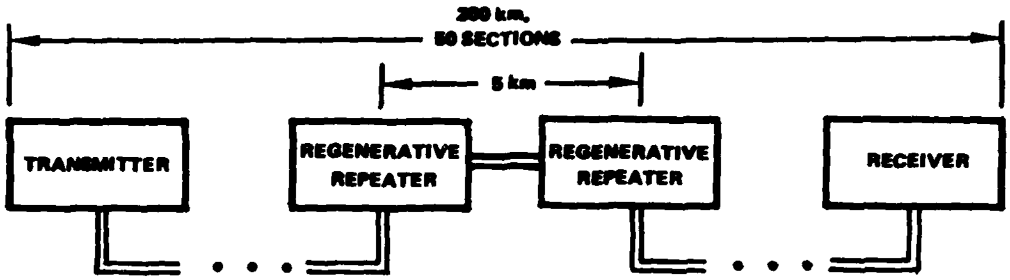


Figure 5.2-1. Postulated Cable Model for Germany

A 200 km 6-tube-cable (2.6/9.5 mm) is used as the reference model for the analysis. The objective for maximum service outage is less than 8.76 hours per year for a 200 km reference link or a time availability of 99.9%.

Table 5.2-2, which is a prediction based on the history (Ref. 5.2-1) of other cable systems, provides a simplified breakdown of the cable outage parameters. Against each failure cause is shown the incident per year, the average tube lost, the mean down time, and service outage per year, all normalized to a 200 km 6-tube-cable reference model. The equation to compute service outage due to cable damange is expressed by:

$$S_0 = I \times (T_L - S) \times T$$

where S_0 = Service outage in hr/year

I = Incidents per year

T_L = Average tube lost

S = Spare tubes, 1 spare tube is assumed

T = Mean down time

From Table 5.2-3, the total service outage is 7.16 hr/year or the time availability is 99.92 percent. The parameters shown in Table 5.2-1 are based on the current coaxial cable systems. By the year 2000, the reliability of coaxial cable and electronic equipment will have improvement without additional cost. We conclude that the proposed system can meet the time availability requirement with 99.9 percent.

Regenerative repeaters are used at regularly spaced (4 km) intervals along the transmission line to reconstruct the digital signal, thereby eliminating the effects of accumulated noise and distortion. The system parameters are listed in Table 5.2-2. The link calculation between repeater and repeater (or transceiver) is the same as Tables 5.1-2 of Section 5.1-3 and will not be repeated here.

Table 5.2-2. System Parameters

System Capacity	Information Transmission Rate	Line: 44.736 Mb/s
	Capacity	Voice: 672 Channel/Line
Line Equipment Design	Transmission Medium	2.6/9.5 mm Coaxial Cable
	Transmission Line Code	Tenary Code m = 3
	Applied Range	100 km
	Repeater Span	4 km
	Repeater Error Rate	10^{-8}/Repeater
	Line Loss	14.6 dB/km @ 40 MHz
	Total Error Rate	Less than 10^{-6}/200 km

Fifty tandem links (each 4 km in length) are necessary to construct a cable link 200 km in length. The bit error rate for 55 tandem links is approximately given by

$$P = 50 P_e$$
$$= 0.5 \times 10^{-6}$$

where P is the BER of the postulated link and is the worst case BEP of any cable link in West Germany, and P_e is the BER of each km cable link.

From the above analysis, we conclude that the proposed cable system can meet the BER requirement with 10^{-6}.

5.2.2.2 Time Availability. In setting the system time availability objective (99.9%), the effects of cable damage and effects of failures from all other sources are treated separately. The major contribution to total unavailability is expected to be cable damage and electronic failure.

Table 5.2-3. Cable Outage of 200 km Model

Failure Cause		Incidents per Year	Average Tube Lost	Mean Down Time (hr)	Service Outage (hr/year)
CABLE	Telephone Co. Activity	0.046	4	5.8	0.80
	Foreign Workman	0.120	4	6.7	2.42
	Lightning	0.030	3	13.0	0.78
	Miscellaneous	0.016	3	9.0	0.28
ELECTRONIC	Multiplex	-	-	-	0.84
	Line Terminal Equipment	-	-	-	0.74
	Line Equipment (e.g. repeater)	-	-	-	0.82
	Miscellaneous	-	-	-	0.48
Total Service Outage					7.16

5.3 SYSTEM PERFORMANCE OF TURKEY TRANSMISSION ALTERNATIVES

The transmission alternatives proposed for Turkey are an EHF satellite system, designated T-1, and an airborne relay system, designated T-2. Performance of these two systems is presented in this section.

5.3.1 System Performance of Transmission Alternative T-1

The EHF satellite link is proposed as one of the alternative systems in Turkey. The satellite link is considered to use 25 ground terminals to replace troposcatter links. The small terminal is defined as one with 2.5 m antenna diameter or less and a transmitter power of 1 KW or less. Central frequencies for up and down link are decided as 30 and 20 GHz, respectively. The modulated information bandwidth B is set to 47 MHz with TDMA operation.

As prescribed in Section 4.4, the propagated EHF wave is subject to absorption caused by oxygen, water vapor, and rainfall. The atmospheric attenuation L_a due to oxygen and water vapor is obtained from Table 4.4-1 with 20^0 elevation angle which is the lowest one in Turkey.

$$L_a = 0.6 \text{ dB} \quad ; \quad \text{uplink } (30 \text{ GH}_z)$$

$$L_a = 0.8 \text{ dB} \quad ; \quad \text{downlink } (20 \text{ GH}_z)$$

Since the attenuation due to other atmospheric effects such as clouds, fog, and snow is negligible compared to rainfall attenuation, these need not be determined. The rainfall attenuation L_r, the most important atmospheric effect, may be estimated from the statistical rainfall data which is shown in Figures 4.4-3 and 4.4-4, where Turkey belongs to region D. The path margin which compensates the rainfall attenuation L_r can be determined for the time availability requirement. The time unavailability due to rainfall is assigned to 5×10^{-3}. It is therefore found from Table 4. 3 that the required path margin is 13 dB and 6 dB for up and downlink, respectively. On the other side, the rainfall attenuation is given by

$$L_r = 13 \text{ dB} \quad ; \quad \text{uplink}$$

$$L_r = 6 \text{ dB} \quad ; \quad \text{downlink}$$

The transmitter circuit loss L_t and the receiver fron end loss L_e

are known to be 2 dB each. With the restriction that the ground terminal is small, the antenna diameter of the ground terminal is set to be 2.5 m. The on-board antenna diameter is suggested to be 0.6 m to cover the entire country. The gain G and beamwidth ϕ of antenna of diameter d are found as follows:

$$G = 0.6 \left(\frac{\Pi}{3}\right)^2 \left(\frac{fd}{10^8}\right)^2 \quad = \quad 55.7 \text{ dB} \quad : \quad \text{ground transmitter}$$

$$= \quad 52.2 \text{ dB} \quad : \quad \text{ground receiver}$$

$$= \quad 43.3 \text{ dB} \quad : \quad \text{on-board receiver}$$

$$= \quad 41.8 \text{ dB} \quad : \quad \text{on-board transmitter}$$

$$\Phi = (1.9)^2 \left(\frac{10^8}{fd}\right) \quad = \quad 0.28^{\circ} \quad : \quad \text{ground transmitter}$$

$$= \quad 0.41^{\circ} \quad : \quad \text{ground receiver}$$

$$= \quad 1.15^{\circ} \quad : \quad \text{on-board receiver}$$

$$= \quad 1.72^{\circ} \quad : \quad \text{on-board transmitter}$$

where f is the central frequency.

The free space loss L_s is given by

$$L_s = 92.5f\ 20 \log f\ (\text{GHz}) + 20 \log D\ (\text{Km})$$

$$L_s = 214.5 \text{ dB} \quad : \quad \text{uplink}$$

$$L_s = 211.0 \text{ dB} \quad : \quad \text{downlink}$$

The received noise power P_n with the noise temperature $T = 1000^{\circ}K$ and the information bandwidth $B = 47\ MH_z$ is given by

$$P_n = 10 \cdot \log KTB = -121.9 \text{ dB}$$

The required signal to noise ratio E_b/N_o for BER = 10^{-6} are given by 10.6 dB. Thus the transmit power P_t which can compensate the free space and atmospheric loss is determined by

$$P_t = L_s + L_r + L_a + L_e + L_t - G_t - G_r + P_n + E_b/N_o$$

$$P_t = 21.8 \text{ dB} \quad : \quad \text{uplink } (30\ GH_z)$$

$$P_t = 16.5 \text{ dB} \quad : \quad \text{downlink } (20\ GH_z)$$

The transmit power 250 watt (24 dB) and 100 watt (20 dB) is enough for the up and downlink to achieve the BER = 10^{-6} requirement, respectively.

The total unavailability due to the path (rainfall attenuation) and terminal (equipment failure) can be estimated by using the Figure 4.4-10. Where the path and terminal availability (1 - unavailability) are set to 99.5% and 99.9%, respectively. Then, the total unavailability is found to be 6×10^{-3}.

The proposed system parameters for Turkey's EHF satellite link are listed in Table 5.3-1.

Table 5.3.1 Proposed System Parameters for Turkey EHF Satellite Link

SYSTEM PARAMETER	UPLINK	DOWNLINK
Frequency	30 GH_z	20 GH_z
Transmitter Power	24 dB (250 Watt)	20 dB (100 Watt)
Transmitter Antenna Gain	55.7 dB (2.5 m)	41.8 dB (0.6 m)
Receiver Antenna Gain	43.3 dB (0.6 m)	52.2 dB (2.5 m)
BER	$< 10^{-6}$	$< 10^{-6}$
Information Bandwidth	47 MH_z	47 MH_z
System Margin	2.2 dB	3.5 dB
Unavailability	$< 6 \times 10^{-3}$	$< 6 \times 10^{-3}$

5.3.2 System Performance of Transmission Alternative T-2

The airborne relay link is proposed as one of the alternative systems in Turkey. Since the area of Turkey is about 767,000 km^2, two airborne platforms and one ground-based processor are needed to relay the messages beyond the distance of line-of-sight. The longest distance between the aircraft and the ground terminal is about 350 km. The same type of aircraft as that of Germany is also suggested for use in Turkey. The central frequencies for up and down link are decided as 7 and 8 GHz, respectively. The modulated information bandwidth is decided as 24 MHz with TDMA operation.

In order to evaluate the system performance, the system gain for the longest distance is obtained.

$$L_s = 92.5 + 20 \log f + 20 \log D$$

$$L_s = 160.3 \text{ dB} \text{ ; uplink (7 GHz)}$$

$$L_s = 161.4 \text{ dB} \text{ ; downlink (8 GHz)}$$

The total waveguide loss L_w for the transmitter and receiver is known to be 1 dB, and the miscellaneous loss L_m was set at 6 dB.

It is expected from the topographic condition and the low elevation angle of the ground terminal antenna that the multipath effect caused by reflection from ground may be serious. Therefore, the realtively high value of 8 dB fade margin is assigned to reduce the multipath effect. The rainfall attenuation L_r is small as shown in the curve 5 (where Turkey belongs) of Figures 4.2-4 and 4.2-5.

There are many DCS sites which communicate with the same aircraft in the north-western part of the country, and some sites are located at relatively short distances from the aircraft. Thus, two different sizes of antennas are suggested to solve the high gain,narrow beamwidth problem. For the long distance, the diameter d = 2.0 m antenna is used, and for the distance shorter than 50 km, the diameter d = 0.6 m antenna is used for the ground terminal. Since the link budget with small antenna and short distance is explained in the case of Germany, the long distance will be presented here. The gain G and the beamwidth Φ of an antenna with

d=2.0 diameter are approximately

$$G = 0.6\ (\frac{\Pi}{3})^2\ (\frac{df}{10^8})^2 = 41.1 \text{ dB} \ ;\ 7 \text{ GH}_z$$

$$\Phi = (1.9)^2 (\frac{10^8}{df}) \qquad = 1.5^o \ ;\ 7 \text{ GH}_z$$

$$= 1.3^o \ ;\ 8 \text{ GH}_z$$

The on-board antenna gain is set at 3dB for its semispheric coverage.

The system gain is given by

$$G_s = L_{fs} + F + L_w + L_m - L_r - G_t - G_r$$

$$= 132 \text{ dB} \ ;\ 7 \text{ GH}_z$$

$$= 132 \text{ dB} \ ;\ 8 \text{ GH}_z$$

The received noise power with the given information bandwidth B = 24 MH_z *is given by*

$$P_n = 10 \log k\ TB = -130 \text{ dB}$$

The receiver noise figure N_F and the required signal to noise ratio E_b/N_o for BER = 10^{-6} are given by

$$N_F = 5 \text{ dB}$$

$$E_b/N_o = 11 \text{ dB}$$

then the required transmitter power is obtained by

$$P_t = G_s + P_n + N_F + E_b/N_o = 19 \text{ dB} \ ;\ 7 \text{ GH}_z \text{and } 8 \text{ GH}_z.$$

Hence, 150 Watt (21.7 dB) transmitter power is enough to achieve the 10^{-6} BER requirement.

In Turkey, two aircraft are used. Since one aircraft may contribute less than 1 x 10^{-4} unavailability as explained in the section on Germany,

the unavailability due to two aircraft is less than 2×10^{-4}, and other atmospheric effects including rainfall are negligible. Thus, the total unavailability is expected to be less than 1×10^{-3}, including equipment failure.

As a result, the proposed system parameter values are listed in Table 5.3-2.

Table 5.3.2 Proposed System Parameters for Turkey Airborne Relay Link

SYSTEM PARAMETER	UPLINK	DOWNLINK
Frequency	7 GH_z	8 GH_z
Transmitter Power	21.7 dB (150 Watt)	21.7 dB (150 Watt)
Transmitter Antenna Gain for Long Distance	41.1 dB (2.0 m)	3 dB
Transmitter Antenna Gain for Short Distance (50 km)	30.8 dB (0.6 m)	3 dB
Receiver Antenna Gain for Long Distance	3 dB	42.3 dB (2.0 m)
Receiver Antenna Gain for Short Distance (50 km)	3 dB	31.8 dB (0.6 m)
BER	$< 10^{-6}$	$< 10^{-6}$
Information Bandwidth	25 MH_z	25 MH_z
Unavailability	$< 10^{-3}$	$< 10^{-3}$
System Margin	2.7 dB	2.7 dB

(THIS PAGE INTENTIONALLY LEFT BLANK)

6.0 COSTS OF ALTERNATIVE TRANSMISSION SYSTEMS

This section presents the results of costing of various alternative transmission systems proposed in Section 5, of Phase IA Report, Evaluation of DCS III Transmission Alternatives. The system design, i.e., some major system parameters of several proposed alternatives have been modified somewhat in the process of system performance evaluation and costing. The proposed alternative transmission systems, as described in Sections 2 and 5 of this document, which include some modifications due to cost consideration, are the base of the costs estimated in this section.

The estimated costs are presented in the following sections and grouped according to the areas of interest. However, considerations and discussions of each alternative transmission system from the view point of system cost is presented along with the system life cycle cost.

6.1 INTRODUCTION

The estimated life cycle for each of the candidate transmission system includes initial deployment costs and projected recurring operations and maintenance expenditures. Costs, which are summarized together with assumptions, restrictions, and corresponding variance parameters, are presented for each of the areas of concern. All costs are projected to the year 2000, in 1980 dollars. Cost reduction due to either advancement or maturing of developing technologies has been forecasted and included in cost estimation.

6.1.1 Cost Projection. The cost of each proposed alternative transmission system includes the following:

1. Initial development cost, if development is unique to the candidate system.

2. Acquisition, deployment and system test cost.

3. Cost of operation, maintenance, and spare parts based on projected support required.

4. Estimate of ten-year life cycle cost.

Cost projection are presented for each of the areas of concern in the following subsections. Cost estimates have been assembled in three ways:

1. Based on use of current (1980) technology, in current (1980) dollars.

2. Based on projected year 2000 technology, in current (1980) dollars.

3. Based on projected year 2000 technology, in year 2000 dollars.

The difference between cost estimates 1 and 2, if there is any, indicates the cost reduction due to technology advancement, in the 20 year period from 1980 to 2000, and the difference between cost estimates 2 and 3 basically reflects inflation in the same period.

Projection of year 1980 costs to year 2000 costs have been made based on a weighted composite of cost factors between the year 1980 to 1990, forecasted by Data Resource Incorporation of non-home construction wage rates based on data supplied by Bureau of Economics Analysis, Department of Commerce. No detailed projected costs of labor or product beyond the year 1990 is currently available. Lacking such projection, simple extrapolation of the same rate increase, as projected for 1980-1990, is used for the year 1991-2000. Using this cost projection, the projected annual rate of increase for year 1980 through year 2000 is 7.3 percent per annum, corresponding to a multiplicative factor of 2.09 for that period. However, this average annual increase rate should be reviewed and revised whenever a new, reliable long-range prediction is available.

Labor costs are assumed to increase by the same factor as discussed above for material and spare parts.

6.1.2 Assumptions and Ground Rules of Costing. In assembly cost estimates, in addition to the projected cost increase as discussed in the last section (Section 6.1.1), some assumptions and ground rates have been consistently applied. These are:

1. Cost estimates are only made for RF transmission media. Multiplexing and demultiplexing equipments are not included according to DCEC instruction, hence, switching equipments are also excluded in the cost estimates presented in the section.

2. The multiplexing format of currently available and developing equipments such as AN/FCC-98 and TD-1193 is assumed. Assumed bit rates of interfaces for insertion, drop, or baseband equipment are either of level 1 rate (1.544 Mbps) or level 2 rates (3.252, 6.464, 9.696, or 12.928 Mbps).

3. Acquisition costs include materials, initial spares, supporting test equipment, system engineering, purchasing, and program management costs necessary to acquire and ship the system components, and detail the installation criteria and instructions. Specifically not included are civil works (buildings, shelters, etc.), power generating equipment and HVAC. It is assumed that all equipments and documentation are produced to best commercial standards.

4. Deployment costs include all labor and associated facilitating costs necessary for the installation, test, and cutover of the systems. These costs do not include acquisition of land, rights-of-ways, etc.

5. Initial development cost is applicable only if development is required and is unique to the candidate system.

6. "1980 dollars" reflects the cost for the system based on common technology assumed to be available in the year 2000; i.e., as though the technology of year 2000 were available today.

7. Life cycle cost is not factored by present value of future value considerations. It is simply total initial cost plus ten times total sustaining cost (per years).

8. "Spares consumption" includes calibration and maintenance costs of test and support equipment as well as replenishment of the initial spares complement.

9. "Operation and maintenance" costs include estimates of labor, and facilitating support, necessary to maintain circuits to normal communications requirements. Special procedures as might be necessary for extreme availability requirements have not been accounted for. It is further assumed that operation and maintenance would be integrated into the existing support structure of the DCS.

10. Sustaining costs include "spares consumption" and "operation and maintenance". Other possible supporting costs, such as power and HVAC.

6.2 ALTERNATIVE TRANSMISSION SYSTEM FOR HAWAII

Two alternative transmission systems are proposed for the Oahu Island of Hawaii. They are buried cable system and millimeter wave line-of-sight relay system and designated as H-1 system and H-2 system respectively. Two options were considered for H-1 buried cable system, namely coaxial tubes and optical fibers. The original motivation of those two options was the following. The cost of armored cables of either coaxial tubes or optical fibers and the labor cost cable burial would constitute the major portion of the system cost. The cost differential of armored cable using either coaxial tubes of optical fibers would be of a small portion of the total system cost. However, the estimated system life cycle cost apparently favors the optical fiber option. This is because of the expected continuous cost reduction for fiber optics and discontinuation of manufacturing of coaxial cables and associated equipment.

6.2.1 Alternative Transmission System H-1. The original proposed millimeter wave system for the Oahu Island was a double star system with two major terminals located at Wahiawa and Pearl Harbor due to the heavy communications capacity loads and geographic nature of the island. However, during the costing exercise, it was found that a mesh system is more appropriate because of:

- Line-of-sight path selection,

- Locating of accessable relay stations,
- Survivability consideration.

The total T1 channel-kilometer of the primary network of the mesh system is of the same order of the original proposed double star system. The primary network can provide all required capacity. The alternative network is to provide redundant routing capability for a portion of the primary network which carries major communications traffics and between the two most important nodes, Wahiawa and Pearl Harbor.

6.2.1.1 <u>H-1 Alternative System Cost Considerations and Assumptions</u>. A millimeter wave line-of-sight digital radio system has been costed for the DCS III alternative transmission system for the island of Oahu. The following assumptions have been applied in developing the costs:

1. Path length between terminals, terminal and repeaters, and repeaters is limited to approximately 5 Km.

2. The digital radio terminal consists of a hot-standby, radio, transmit power amplifier, single antenna, interconnecting waveguide and cable, suitable packaged. The interface with the multiplexer equipment is a high-data rate (up to 60 Mbps) bit stream. The terminal will be powered from existing site power distribution system.

3. The digital radio repeater consists of two hot-standby terminals connected as a baseband repeater. The repeater is powered from batteries charged from solar cells or utility power.

4. At each interconnect site, there will be one hot standby digital radio terminal for each of the links accessing the site. The terminals will be powered from the existing site power distribution system.

5. The terminals (including those at interconnect sites) and repeaters are tower or pole mounted on buildings or at suitable sites. The height of the towers and/or poles would be determined by the required antenna elevations for line-of-sight clearances.

6.2.1.2 H-1 System Site Selection. A study has been conducted to select interconnect points and repeater sites for the millimeter wave line-of-sight system for the Oahu Island. The system will serve as an alternative transmission media for performance and cost tradeoff comparisons with the hypothesized cable (coaxial tubes and optical fiber) system.

To determine the DCS locations, DCA circular 310-65-1 (Ref. 6.2-1) was used. The locations were plotted on a U. S. Geological Survey topographic map of the Island of Oahu, shaded relief edition, with a scale of 1:62,500.

In determining the repeater locations and interconnection points required for the system, the same map was used, supplemented by the shaded vegetation edition. The following factors were considered in the selection of the repeater locations:

1. The terrain and vegetation will not obstruct 0.6 of the first fresnel zone in a standard atmosphere using 100 ft. (30 m.) antenna heights.
2. Sites will be on U. S. Government owned land where possible.
3. Sites will be accessable by roadways where possible.
4. Sites will be clear of vegetation where possible.
5. Radio paths will not cross airfields.
6. Radio path lengths will not exceed 6.5 kilometers.

The DCS terminals, repeaters, and interconnection points have been identified and their locations are shown in Figure 6.2-1. It is not coincident that the line-of-sight path of the millimeter wave system is quite similar to that of the buried cable system described in Section 6.2.2. It is because of the geographic and topographic features of the Island of Oahu.

Table 6.2-1 lists the required repeater sites and associated information. Table 6.2-2 shows the quantity required for network elements.

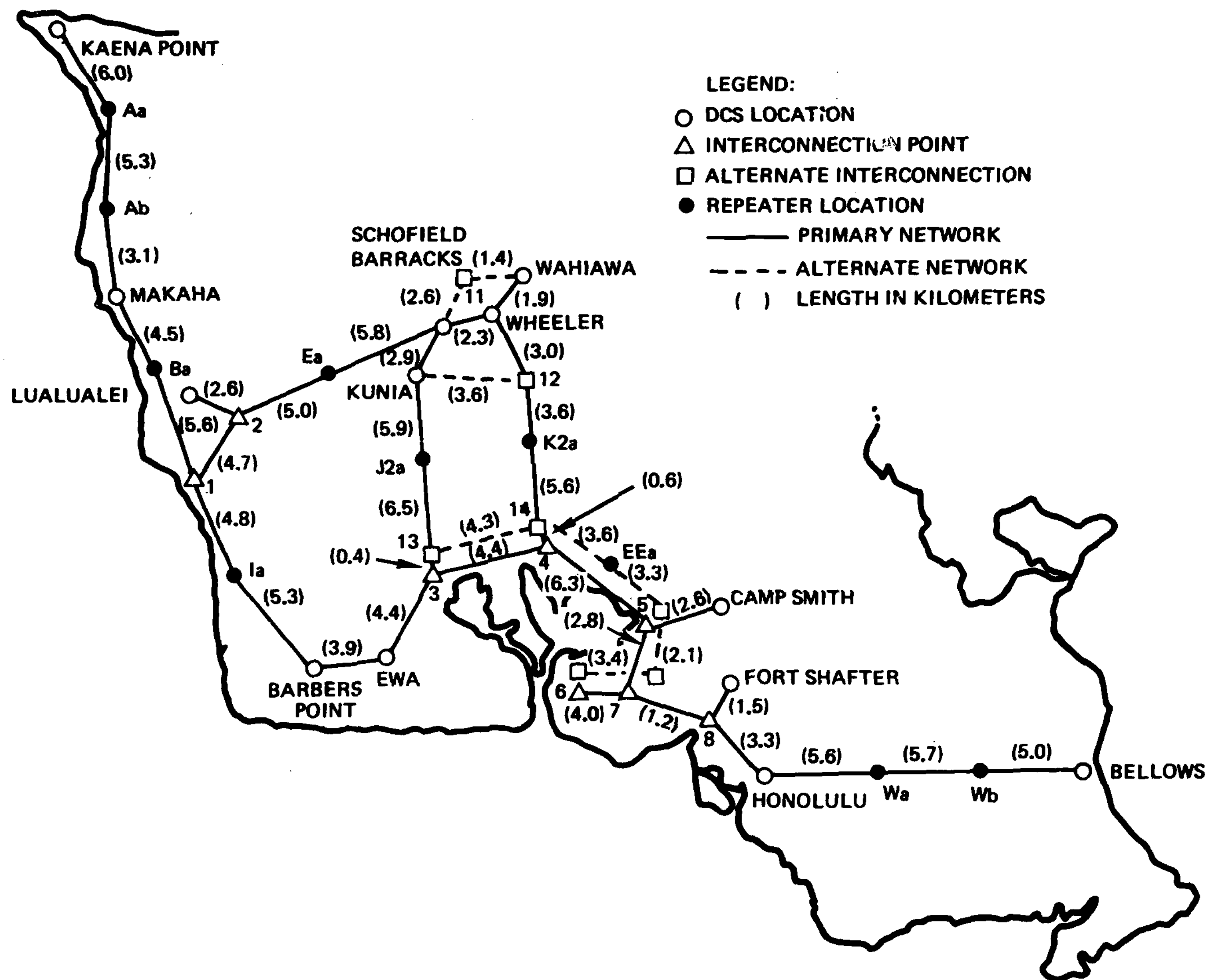


Figure 6.2-1. Millimeter Wave System of Oahu Island

Table 6.2-1. Repeater for Millimeter Wave LOS System, Oahu, Hawaii

Network Branch Designation	No. of Repeaters Required	Repeater Designators	Repeater Locations	Comments
A	2	Aa	21° 32'21"N	12m. AMSL, Military Reservations at Makaia
			158° 13'56"W	along Farrington Highway (Unimproved dirt)
		Ab	21° 29'35"N	524m. AMSL, tree covered hilltop bordering
			158° 13'00"W	Makau Keaau Forest Reserve; trail access
B	1	Ba	21° 26'08"N	220m. AMSL, tree covered hilltop at
			158° 10'50"W	Puu Mailiilii, difficult access
E	1	Ea	21° 27'27"N	382m. AMSL, cleared hilltop at
			158° 05'25"W	Puu Kanehoa, difficult access
I	1	Ia	21° 21'20"N	146m. AMSL, cleared hilltop near
			158° 07'41"N	Kahe Point, trail access
J2	1	J2a	21° 25'58"N	252m. AMSL, cleared hilltop in Honouliuli
			158° 03'56"W	Forest Reserve, light-duty road access
K2	1	K2a	21° 27'05"N	212m. AMSL, cleared hilltop in Military
			158° 59'41"W	Reservation, along unimproved dirt roadway
EE	1	EEa	21° 23'35"N	9m. AMSL, Naval Reservation at Waiau,
			157° 57'46"W	along Kamehameha Highway (heavy-duty roadway)
W	2	Wa	21° 20'10"N	614m. AMSL, tree covered hilltop at Tantalus,
			157° 49'03"W	near light-duty roadway
		Wb	21° 20'05"N	799m. AMSL, partially tree covered hilltop
			157° 45'44"W	at Puu Lanipo, difficult access

Note: Except branches listed above, no other network branch needs repeater.

AD-A101 363 TRW DEFENSE AND SPACE SYSTEMS GROUP REDONDO BEACH CA F/G 17/2.1
EVALUATION OF DCS III TRANSMISSION ALTERNATIVES, PHASE 1B. FINA--ETC(U)
SEP 80 T M CHU DCA100-79-C-0044
UNCLASSIFIED TRW-35142 SBIE-AD-E100 403 NL

3 OF 3
AD
A101363

END
DATE
FILMED
8-81
DTIC

Table 6.2-2. Millimeter Wave Network Elements

NETWORK ELEMENT	QUANTITY
Network Branches	30
Terminal Sites	14
Terminals (including Interconnection terminals)	46
Repeaters	9

6.2.1.3 Millimeter Wave LOS Digital Radio Equipment. Communication at millimeter wave during the period to year 2000 will steadily increase as more bandwidth is required for the very high data rate carriers, and the lower common carrier frequency bands become saturated. From now on, it should see a dramatic increase in development leading to production of millimeter wave radio equipment. Production digital equipment is not available at the present time and development money has to be spent on designing and developing bandwidth efficient modems, power amplifiers, low noise amplifiers, and stable frequency sources.

It is estimated that in 1980 it would require one million dollars to develop a millimeter wave terminal with the production cost per terminal being one hundred thousand dollars, in large quantities. By 1985 the development cost would reduce to two hundred thousand dollars because of parallel development work by different companies. It is estimated that by the year 2000, millimeter wave radio equipment will be fully developed and commercially available at a cost of forty thousand dollars (1980 dollars) in unit quantities.

Millimeter wave test equipment is not available in 1980 in production quantities. Development of the radio equipment is dependent upon the availability of suitable test equipment. Test equipment manufacturers will develop the test equipment to meet the requirements

of the millimeter wave radio equipment manufacturers and the potential market to support the applications. Therefore, development dollars need not be included in the cost projections by the year 2000; millimeter wave test equipment will be readily available.

6.2.1.4 Maintenance Philosophy. It is assumed that the bulk of the test equipment, including the major items and seldom used items, will be located at one central maintenance and storage facility. More frequently used test equipment items will be available at each terminal and interconnecting site for minor maintenance and operation. Maintenance teams would perform site, link and system testing by drawing from the test equipment inventory at the central facility.

6.2.1.5 H-1 Alternative System Cost. The millimeter wave line-of-sight relay system has been costed. The results are shown in Tables 6.2-3, 6.2-4, and Tables 6.2-5, 6.2-6 for primary network and secondary network, respectively. The acquisition costs for these two networks shown in Tables 6.2-3 and 6.2-5 are further broken down and tabulated in Tables 6.2-4 and 6.2-6, respectively, for primary and auxiliary network.

6.2.2 Alternative Transmission System H-2. As stated previously, two options, coaxial tubes and optical fibers, were considered as media for the Hawaii buried cable system. However, the primary and auxiliary cable nodes are the same for the two options and are shown in Figure 6.2-2.

6.2.2.1 H-2 System Coaxial Cable Option Technology Considerations. A survey of cable and equipment manufacturers and suppliers has been conducted to determine the technology presently available for digital transmission over coaxial cable. Although coax has been used extensively for frequency division multiplexed voice channels, there has been little effort devoted to the development of coaxial systems for digital traffic.

Table 6.2-3. Summary Costs for Hawaii Millimeter Wave LOS System, Primary Network

COST ITEM	1980 TECHNOLOGY 1980 DOLLARS	2000 TECHNOLOGY 1980 DOLLARS	2000 TECHNOLOGY 2000 DOLLARS
Initial Development	1,500		
Acquisition	18,447	5,379	22,000
Deployment	3,196	1,598	6,536
Total Initial Cost	23,143	6,977	28,536
Operation/Maintenance Cost (p.a.)	808	321	1,313
Spares Consumption (p.a.)	1,151	240	982
Total Sustaining Cost (p.a.)	1,959	561	2,298
Ten-Year Life Cycle Cost	42,733	12,587	51,481

Table 6.2-4. Acquisition Cost for Hawaii (1980 Dollars) Millimeter Wave LOS System, Primary Network

COST ITEM	YEAR 1980 TECHNOLOGY	YEAR 2000 TECHNOLOGY
Radio Equipment	14,336	4,096
Towers, Poles, etc.	31	31
Integration & Installation Material	253	169
Test Equipment	1,505	502
Initial Spares	2,322	581
Total Acquisition Cost	18,447	5,379

Table 6.2-5. Summary Costs for Hawaii Millimeter Wave LOS System, Auxiliary Network

COST ITEM	1980 TECHNOLOGY 1980 DOLLARS	2000 TECHNOLOGY 1980 DOLLARS	2000 TECHNOLOGY 2000 DOLLARS
Initial Development	--	--	
Acquisition	5,470	1,594	
Deployment	825	413	
Total Initial Cost	6,295	2,007	
Operation/Maintenance Cost (p.a.)	240	95	
Spares Consumption (p.a.)	581	71	
Total Sustaining Cost (p.a.)	821	166	
Ten-Year Life Cycle Cost	14,505	3,667	14,998

Table 6.2-6. Acquisition Cost for Hawaii Millimeter Wave LOS System, Auxiliary Network

COST ITEM	YEAR 1980 TECHNOLOGY	YEAR 2000 TECHNOLOGY
Radio Equipment	14,336	4,096
Towers, Poles, etc.	31	31
Integration & Installation Material	253	169
Test Equipment	1,505	502
Initial Spares	2,322	581
Total Acquisition Cost	18,447	5,379

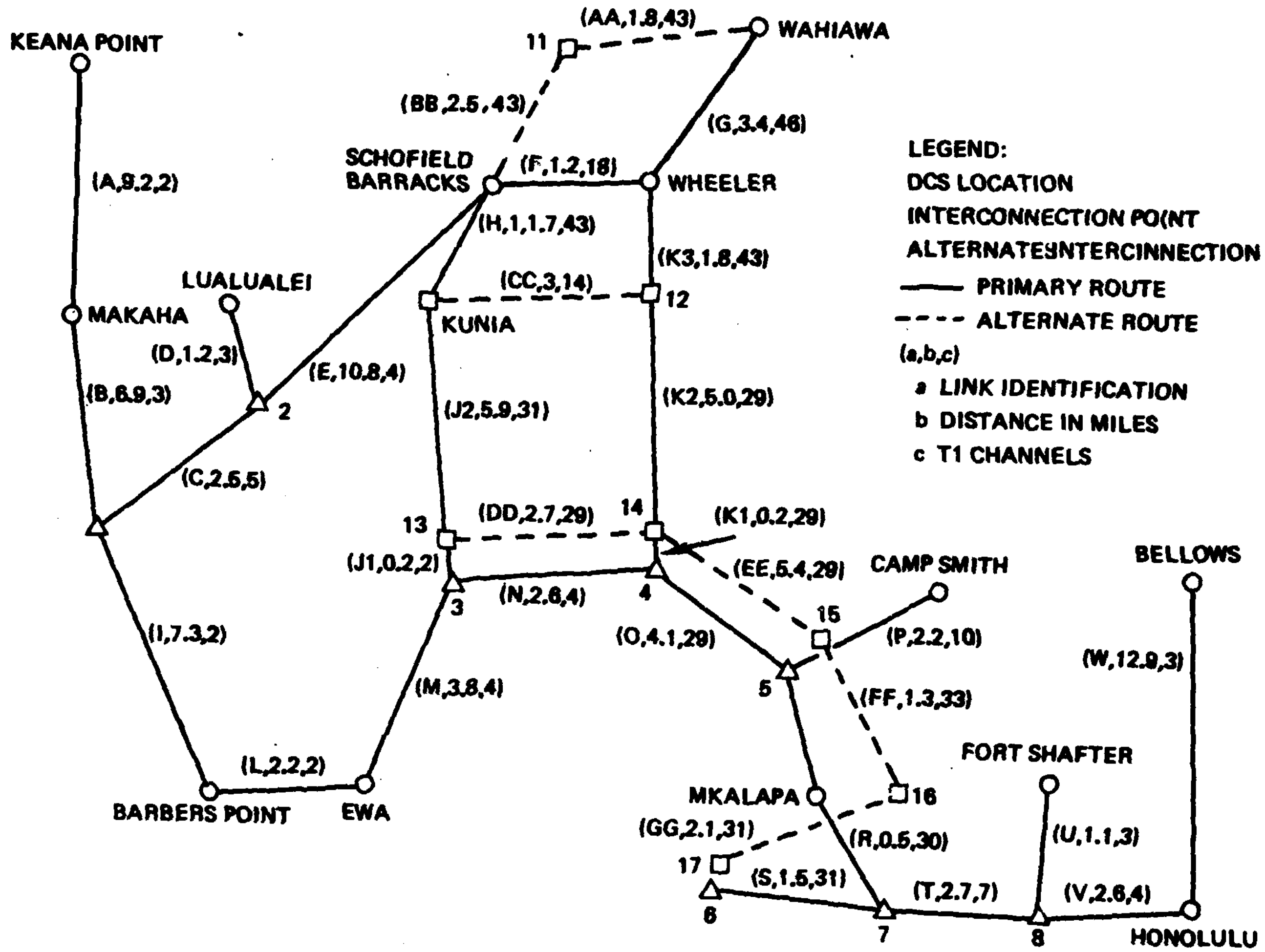


Figure 6.2-2. Cable System of Oahu Island

One technique available for use is to process the digital signal by means of a modem to produce and analog signal which can be transmitted over an FDM coaxial cable system. However, this technique is not recommended since the signal is only amplified, as opposed to being regenerated, at repeater locations along with the accumulated noise introduced by the cable. This defeats one of the major advantages of digital transmission - the ability of the digital repeater to regenerate a clean signal.

Equipment recently developed which does take advantage of the regenerative characteristics of the digital repeater is intended to be retrofitted into existing L-3, L-4 and L-5 coaxial carrier transmission systems for 45, 135 and 360 Mbs duplex operation, respectively. The L-3 system utilizes twelve coaxial tubes with five working tubes and one protect tube for each direction with regenerative repeaters spaced at approximately four mile intervals. This configuration is suitable for the coaxial cable routes in Hawaii and Germany. The T-1 channel requirements in both regions could be accomplished by one L-3 system or two parallel L-3 systems with ample growth capability.

The results of the survey also indicates that there are virtually no R&D efforts being funded for digital transmission over coaxial cable. This is partly because the coaxial medium requires pressurization and repeaters while these factors are absent for the optical fiber medium. More important, it is presently more cost effective to use optical fiber; further, the cost of optical fiber systems continues to decline.

It is the unanimous opinion of those surveyed that:

1. During the decade of the 1980's fiber-optic technology will be completely supplemented coaxial cable technology for new installations requiring digital transmission.

2. Current interest in digital transmission over coaxial cable is almost entirely directed toward upgrade of existing plant from analog to digital transmission. Current available and planned equipment for digital transmission over coaxial cable is intended for this purpose, as opposed to new installations.

Consequently, the most optimistic projections that can be made concerning coaxial cable technology in the year 2000 is that equipment intended for coaxial plant upgrade can be used for new installation, and will still be available (along with coaxial cable itself) at that time at the equivalent of current cost levels.

The coaxial cable system proposed for the Island of Oahu consists of equipment designed to be retrofitted to an L-3 coaxial-carrier transmission system. The cable itself consists of twelve coax tubes wrapped in a PVC protective sheath. Figure 6.2-2 shows the logical connections of the links required to support user needs.

Of the twenty-six primary coaxial links, sixteen require one L-3 system while the remaining ten need two parallel L-3 systems. Since cable lengths cannot exceed four miles without repaters, seven man-holes are required to house the repeater equipment.

For the auxiliary network, six of the seven links require parallel L-3 systems with one L-3 system needed for the remaining link. Only one man-hole is required for the auxiliary network.

6.2.2.2 <u>H-2 System Coaxial Cables Option System Cost</u>. The life-cycle of coaxial tubes options of Hawaii alternative transmission system is shown in Tables 6.2-7 and 6.2-9, respectively, for primary network and auxiliary network. Breakdown of acquisition cost for both networks is tabulated in Tables 6.2-8 and 6.2-10, respectively. Note that system costs expressed in 1980 dollars for both 1980 technology and 2000 technology are the same because it has been assumed that no significant technology advancement would be made in this period for digital coaxial cable transmission system. Furthermore, the primary network is capable of carrying all communication traffic, and the auxiliary network is included to provide redundant routes for the heavy needs between Wahiawa, Wheeler, and Pearl Harbor.

6.2.2.3 <u>H-2 System Optical Fiber Option Technology Considerations</u>. Communication transmission by fiber optic cables, in 1980, is a relatively immature technology. During these past five years, tremendous progress has been made, but much more progress will have been achieved by the year 2000, defined as the timeline for the projected DCS III Alternative Transmission System.

Table 6.2-7. Summary Costs for Hawaii Coaxial Cable System, Primary Network

COST ITEM	1980 TECHNOLOGY 1980 DOLLARS	2000 TECHNOLOGY 1980 DOLLARS	2000 TECHNOLOGY 2000 DOLLARS
Initial Development	---	---	---
Acquisition	37,250	37,250	152,353
Deployment	10,868	10,868	44,450
Total Initial Cost	48,118	48,118	196,803
Operation/Maintenance Cost (p.a.)	204	204	834
Spares Consumption (p.a.)	2,211	2,211	9,043
Total Sustaining Cost (p.a.)	2,415	2,415	9,877
Ten-Year Life Cycle Cost	72,268	72,268	295,573

Table 6.2-8. Acquisition Cost for Hawaii Coaxial Cable System, Primary Network (1980 Dollars)

COST ITEM	YEAR 1980 TECHNOLOGY	YEAR 2000 TECHNOLOGY
Line Terminating Equipment	20,865	20,865
1:5 Protection Switch	4,802	4,802
Repeaters and Supervisory Alarms	850	850
Repeater Housings	455	455
Coaxial Tubes in PVC Sheath	4,835	4,835
Test Equipment	460	460
Initial Spares	5,394	5,394
Total Acquisition Cost	37,250	37,250

Table 6.2-9. Summary Costs for Hawaii Coaxial Cable System, Auxiliary Network

COST ITEM	1980 TECHNOLOGY 1980 DOLLARS	2000 TECHNOLOGY 1980 DOLLARS	2000 TECHNOLOGY 2000 DOLLARS
Initial Development	---	---	---
Acquisition	12,292	12,292	50,274
Deployment	2,025	2,025	8,282
Total Initial Cost	14,317	14,317	58,556
Operation/Maintenance Cost (p.a.)	21	21	86
Spares Consumption (p.a.)	851	851	3,481
Total Sustaining Cost (p.a.)	872	872	3,567
Ten-Year Life Cycle Cost	23,037	23,037	94,226

Table 6.2-10. Acquisition Cost for Hawaii Coaxial Cable System, Auxiliary Network (1980 Dollars)

COST ITEM	YEAR 1980 TECHNOLOGY	YEAR 2000 TECHNOLOGY
Line Terminating Equipment	7,534	7,534
1:5 Protection Switch	1,734	1,734
Repeaters and Supervisory Alarms	141	141
Repeater Housings	34	34
Coaxial Tubes in PVC Sheath	958	958
Test Equipment	---	---
Initial Spares	1,889	1,889
Total Acquisition Cost	12,292	12,292

Currently (1980), the technology exists as required for both the Hawaii and Central Germany cable systems. Fiber optic links of five or more kilometers and operating up to DS-3 (45 Mbps) are commonplace. Major telecommunications suppliers, such as Western Electric, GTE-Lenkurt and NEC, have announced production equipment intended for DS-3 transmission between central office exchanges, requiring circuit spans in the range of 2 to 5 kilometers, with repeater spacing varying between 5 and 10 kilometers depending on required bandwidth and other factors. Such performance capabilities can easily accommodate the projected DCS III needs for Hawaii. It is considered that the technology and techniques necessary for installation, including splicing and connectorization, is sufficiently well developed even at present for the future requirements.

Because fiber optics technology is currently at an early point on the maturation curve, however, major advances by the year 2000 will have impact on this projected DCS III alternative. The impact will be measured in terms not only of system performance parameters, but also costs, and ease of intallation and maintenance. The following discussion briefly outlines the basis of our projections of technology and cost.

Current transmitters and receivers, and their associated circuitry are being produced in relatively small quantities, and are implemented with discrete components particularly in the analog portions. Well before the year 2000, integration of these units will occur. Multiple emitters (e.g., injection-diode lasers) and detectors (e.g., avalanche photodiodes) will be available in monolithic packages. Initial development work to this end is already known to be underway in Bell Laboratories, GTE, NEC, Philips Research Labs and Siemens. The net result will be a decrease in size and cost, and an increase in reliability. For example, the projected MTBF of a link is 200,000 hours.

By analogy with the experience curves for both digital and analog integrated circuitry, a decrease in cost by a factor of 20, over the next 20 years, can be conservatively projected. Further supporting this estimate are the economies of scale to be realized by the greatly increased production quantities projected for these units.

Operating parameters foreseen for the future are based on current advanced work. Present-day fiber optic systems operate in the region of 850 nm wavelength, largely determined by the characteristics of early emitters. It is now well known that fiber losses and material dispersion are much lower when operated at wavelengths in the vicinity of 1.3 microns. At that wavelength, repeaterless transmission has already been demonstrated at 45 Mpbs over a span of 55 Km. Such performance will be standard by the year 2000. Since all individual links in Hawaii are less than this distance, no repeaters have been incorporated in the network design.

Concomitant with the adoption of longer wavelength transmission, it is anticipated that the present trend toward monomode fibers will continue. One result is that modal dispersion will be minimized (theoretically reduced to zero), thus allowing transmission of an extremely large bandwidth. Another result is lower-cost fiber which, when combined with the much larger expected production volumes, will provide low-cost optical fiber cables. Cables made up of standard fibers of 10 micron diameter which will cost $0.25 per meter (one-quarter the cost of current cables containing graded-index fibers of 50 micron diameter) are anticipated. Matching optical devices, such as bidirectional couplers, will be commonly available.

Technological advances and volume production will also have a favorable impact on ancillary costs, e.g., test equipment. A cost shrinkage of 1:5 in 1980 dollars has been projected for such equipment as bit-error-rate testers, time-domain reflectometers and "Photodyne Multimeters".

6.2.2.4 H-2 System Optical Fiber Option System Design. The network topology of the optical fiber option is the same as that of coaxial tubes option and is shown in Figure 6.2-2. The auxiliary network, as indicated by dashed lines in that figure, is recommended to enhance network reliability and survivability. For the reasons discussed in the last section, no repeaters are necessary. Electro-optical transmitters/receivers are located at each terminal site; each link terminal is estimated to occupy 2.7 m elevation in a standard equipment

rack. The transmitter/receiver units have a built-in monitor which warns 1000 hours ahead of the failure, if the power levels or sensitivity levels fall below the set levels for reliable operation. The design incorporates a built-in 1 x 1 protection system which automatically switches data over to the redundant electro-optic system as soon as the power monitor alarm indicates the deterioration of optical power. During 1000 hours one can replace the faulty system.

The cable to be used is made up with an integral armor sheathing, and is reinforced and water tight. Thus, the cable is suitable for direct burial. It is assumed, however, that 50 percent of the cable runs with transit areas where additional PVC duct is necessary for pulling and/or for additional protection, and that some portions will be best installed by the aerial method. Acquisition costs include additional materials.

In the system design for 1980 technology, fibers having a loss of 1 dB/km at 1.3 microns has been used. Splices will be made at 1.5 km intervals, and will contribute a loss of 0.5 dB each. The longest link in Hawaii is about 21 km; thus an engineering loss (not including margin) of 35 dB will be experienced. This can be accommodated with current transmitter/receiver technology, as no repeaters are required for the Hawaii network.

For year 2000 technology, it can be assumed that fiber loss is 0.1 dB/km, and splice loss is 0.15 dB.

6.2.2.5 <u>H-2 System Optical Fiber Option System Cost</u>, System life cycle costs for primary and auxiliary networks are displayed in Tables 6.2-11 and 6.2-13, respectively. Acquisition costs for these two networks are tabulated in Tables 6.2-12 for the primary network and 6.2-14 for the auxiliary network.

Table 6.2-11. Summary Costs for Hawaii Optical Fiber System, Primary Network

COST ITEM	1980 TECHNOLOGY 1980 DOLLARS	2000 TECHNOLOGY 1980 DOLLARS	2000 TECHNOLOGY 2000 DOLLARS
Initial Development	100	---	---
Acquisition	4,829	1,417	5,796
Deployment	7,245	6,521	26,670
Total Initial Cost	12,174	7,938	32,466
Operation/Maintenance Cost (p.a.)	264	183	748
Spares Consumption (p.a.)	259	28	115
Total Sustaining Cost (p.a.)	523	211	863
Ten-Year Life Cycle Cost	17,404	10,048	41,096

Table 6.2-12. Acquisition Cost for Hawaii Optical Fiber System, Primary Network (1980 Dollars)

COST ITEM	YEAR 1980 TECHNOLOGY	YEAR 2000 TECHNOLOGY
Cable, Fiber Optic	1,222	309
Duct/Aerial Subsystem	759	759
Electro-Optic TX/RX	2,114	211
Couplers & Connectors	76	38
Initial Spares Complement	458	40
Test Equipment	200	60
Total Acquisition Cost	4,829	1,417

Table 6.2-13. Summary Costs for Hawaii Optical Fiber System, Auxiliary Network (1980 Dollars)

COST ITEM	1980 TECHNOLOGY 1980 DOLLARS	2000 TECHNOLOGY 1980 DOLLARS	2000 TECHNOLOGY 2000 DOLLARS
Initial Development			
Acquisition	1,123	289	
Deployment	1,350	1,215	
Total Initial Cost	2,473	1,504	
Operation/Maintenance Cost (p.a.)	37	23	
Spares Consumption (p.a.)	36	4	
Total Sustaining Cost (p.a.)	73	27	
Ten-Year Life-Cycle Cost	3,203	1,774	7,256

Table 6.2-14. Acquisition Cost for Hawaii Optical Fiber System, Auxiliary Network (1980 Dollars)

COST ITEM	YEAR 1980 TECHNOLOGY	YEAR 2000 TECHNOLOGY
Cable, Fiber-Optic	230	58
Duct/Aerial Subsystem	161	161
Electro-Optic TX/RX Subsystem	591	60
Couplers	14	1
Connecting Devices	5	1
Initial Spares	122	8
Total Acquisition Cost	1,123	289

6.3 ALTERNATIVE TRANSMISSION SYSTEMS FOR GERMANY

Two alternative transmission systems were proposed for central Germany in Section 5.4 of the Final Report of Evaluation of DCS III Transmission Alternatives. These two systems, designated G-1 and G-2 employing an airborne relay platform and buried cables, respectively, have been briefly described in Sections 2 and 4 of this report. Modifications made to system designs during the evaluation and costing processes are included in the system descriptions. The alternative system G-1 employs a tethered balloon which is one of the platform specified for the study. The size of the central Germany of interest is particularly suitable for a tethered balloon operating at an altitude of 4,573 m (15,000 ft). Other types of airborne platforms are also possible. For example, a manned or unmanned aircraft can also be used as a platform. The L-450 F aircraft of E-system is of the right size, weight, payload, and endurance; therefore, a life-cycle cost estimated for a system using L-450 F aircraft was also made and included for comparison. However, the use of an airborne platform for relay which is an unconventional approach for day-to-day communications needs has its own merits and disadvantages.

The alternative transmission system G-2 is proposed with the assumption that joint use and cost sharing of the buried cable system would be made with the German Government. This joint approach is suggested to facilitate implementation of the program, particularly laying the cables.

6.3.1 Alternative Transmission System G-1. The airborne relay system is designed based on using either a tethered balloon, Aerostats CBV250A of Sheldahl or an aircraft, L-450 of E-Systems. The same communications requirements has been assumed for this system as is used for the cable system alternatives. Some technology and costing considerations are discussed in the following subsection.

6.3.1.1 Airborne System Costing Assumptions. The projected cost for the proposed airborne relay system is based on the following assumptions:

1. A tethered balloon or an aircraft with on-board communications equipment to serve as an airborne relay station to ground stations operating in the frequencies of 7 GHz (uplink) and

8 GHz (downlink) will be provided as part of the system cost. A total of four airborne platforms has been costed for each system; one operational, one standby, the third for routine maintenance, and the fourth for emergency.

2. A ground station at each of 22 communicaton nodes. Each of these nodes would be collocated with terrestrial facilities and made use of existing building/shelters and prime power distribution.

3. A high data rate single carrier time division multiple access (TDMA) scheme would be used.

4. Multiplexer equipment is not included. The interface would be the data input/output ports of the TDMA terminals at DRAMA level 1 or level 2.

5. All equipment is best quality commercial.

6.3.1.2 Tethered Balloon System. Currently Sheldahl, Advanced Products Division in Northfield, Minnesota is manufacturing two of the largest state-of-the-art tethered balloons for use as a stable airborne platform. These have nominal volumes of 250,000 cubic feet and 365,000 cubic feet, known as the CBV250A and CBV365A, respectively. The configuration of the mooring and servicing machinery is similar for both sizes. The CBV250A is adequate to carry the communications payload and is used for relay platform. Four balloons are assumed for ten years continuous operation with replenishing helium and patching included in normal operating cost.

Information and costing is based upon information from Sheldahl, TCOM and USAF (Patrick AFB, Florida).

6.3.1.3 Aircraft. Any high performance and long endurance aircraft can be employed as airborne relay platform. However, some aircraft have difficulties in being used for a relay platform. Three major difficulties are the high operation cost, high-altitude flying with small radius of circle, and operational and maintenance problems. A currently available aircraft suitable for the relay platform is E-Systems L-450, which can be operated as either a remotely piloted vehicle or manned aircraft. E-Systems pointed out that manned systems significantly improve cost effectiveness over unmanned mode of operation. Therefore, the cost estimation is based

on the manned operation. But it is expected from the trend of technology improvement that unmanned operation will be feasible with the same operational cost as the manned operation in the near future.

6.3.1.4 Airborne Relay Station and Ground Station. The relay station is fully redundant for maximum reliability with in-line switching available for automatic or remote selection of operation equipment. The ground station is also fully redundant with automatic switching between on-line and standby equipment chains. Except for the on-board antenna and TDMA terminals, the communications equipment is of conventional design. The antenna requires very wide beamwidth (170^{o}), and may demand that the required ground coverage be sectionized and a multiple antenna system be developed. By the year 2000, it is a reasonable assumption that TDMA will be the standard satellite access technique, and this technology can be applied to the airborne relay system ground stations with little or no modification.

6.3.1.5 G-1 Airborne Relay System Cost. Tables 6.3-1 and 6.3-2 show the cost of the tethered balloon relay system including ground stations. The 1980 cost of the balloon, the tether, mooring platform and ancillary equipment, has been estimated after considerable discussion with manufacturers and users in the armed services.

Tables 6.3-3 and 6.3-4 give the cost of the aircraft relay system including ground stations.

The aircraft operational and initial cost is based on the E-Systems estimation that a fleet of 42 aircraft will be able to provide continuous operation of 12 sites in a time period of eight years. The above cost is prorated for the present purpose of one aircraft continuously on-air.

The 1980 price of year 2000 technology as listed in these tables shows a reduction in cost for the communications equipment. This is because of the impact of LSI and lower number of individual parts making up the system. The aircraft price and its operational cost are anticipated not to be reduced.

Table 6.3-1. Summary Costs for German Airborne Relay System, Tethered Balloon Option

COST ITEM	1980 TECHNOLOGY 1980 DOLLARS (K)	2000 TECHNOLOGY 1980 DOLLARS (K)	2000 TECHNOLOGY 2000 DOLLARS (K)
Initial Development	500	250	1,022
Acquisition	41,426	30,757	125,796
Deployment	13,176	11,858	48,499
Total Initial Cost	55,102	42,865	175,318
Operation/Maintenance Cost (p.a.)	1,610	1,449	5,926
Spares Consumption (p.a.)	1,373	917	3,750
Total Sustaining Cost (p.a.)	2,983	2,366	9,677
Ten-Year Life Cycle Cost	84,932	66,525	272,088

Table 6.3-2. Acquisition Cost for German Airborne Relay System, Tethered Balloon Option (1980 Dollars)

COST ITEM	YEAR 1980 TECHNOLOGY	YEAR 2000 TECHNOLOGY
(22) TDMA Ground Stations	21,724	12,904
(4) Aerostats	10,000	10,000
(4) Relay Communications Equipment	2,088	1,672
Tether and Mooring Platforms	4,000	4,000
Communications Test Equipment	1,738	1,148
Initial Spares Complement	1,876	1,033
Total Acquisition Cost	41,426	30,757

Table 6.3-3. Summary Cost for German Airborne Relay System, Aircraft Option

COST ITEM	1980 TECHNOLOGY 1980 DOLLARS	2000 TECHNOLOGY 1980 DOLLARS	2000 TECHNOLOGY 2000 DOLLARS
Initial Development	500	250	1,022
Acquisition	42,837	30,302	147,873
Deployment	8,036	6,532	26,702
Total Initial Cost	51,373	37,084	175,597
Operation/Maintenance Cost (P.A.)	3,073	2,466	12,592
Spares Consumption (P.A.)	618	314	1,284
Total Sustaining Cost (P.A.)	3,691	2,780	13,876
Ten-Year Life Cycle Cost	88,283	64,884	314,357

Table 6.3-4. Acquisition Cost for German Airborne Relay System, Aircraft Option (1980 Dollars).

COST ITEM	YEAR 1980 TECHNOLOGY	YEAR 2000 TECHNOLOGY
(22) TDMA Ground Station	21,724	12,904
(4) Aircraft	8,869	8,869
(4) Relay Communications Equipment	2,088	1,672
Airborne Ground Equipment	6,670	4,536
Communication Test Equipment	1,876	1,033
Initial Spares	1,610	1,288
Total Acquisition Cost	42,837	30,302

6.3.2 Alternative Transmission System G-2. The network topology for the buried cable system for central Germany is shown in Figure 6.3-1. The actual cable route is shown in Figure 2.3-5 of Section 2.3-2. Like the Hawaii Cable system, both coaxial tubes and optical fibers options were considered.

6.3.2.1 G-2 System Coaxial Cable Option Technology Consideration. The DCS node locations and interconnection points for central West Germany of interest are shown in Figure 6.3-1. The total system is made up of more than 580 km of transmission, consisting of 526 and 68 km for the primary and auxiliary network, respectively. Equipment designed for retrofitting to an L-3 coaxial-carrier transmission system is recommended. The cable itself has twelve coax tubes wrapped in a PVC protective sheath.

Thirty-five routes are proposed for the primary network. Of these, only three require two parallel L-3 systems to support user needs while the remaining thirty-two routes require a single L-3 system. With repeaters necessary for the longer routes, nine man-holes are needed.

The auxiliary network routing consists of seven paths, two requiring two parallel L-3 systems and five utilizing a single L-3 system. Eleven man-holes are needed for the alternate routes.

As compared with Hawaii, buried cable costs on a per-kilometer basis will be higher in Germany for several reasons. The cable route will traverse more areas characterized by higher population density and greater existing development. It can be expected that greater difficulty will be experienced in satisfactory cable placement, and more installation materials will be consumed en route due to special duct protection measures, surface repair with concrete and asphalt, etc. Offsetting this to some degree in life-cycle costs is the anticipated higher efficiency in utilization of maintenance personnel.

6.3.2.2 System Cost of G-2 System Coaxial Cable Option. The system life-cycle cost of primary network of the buried cable alternative transmission system, coaxial tube option is given in Table 6.3-5 and the acquisition cost in Table 6.3-6. For the auxiliary network, Tables 6.3-7 and 6.3-8 tabulate the system life-cycle cost and acquisition cost respectively.

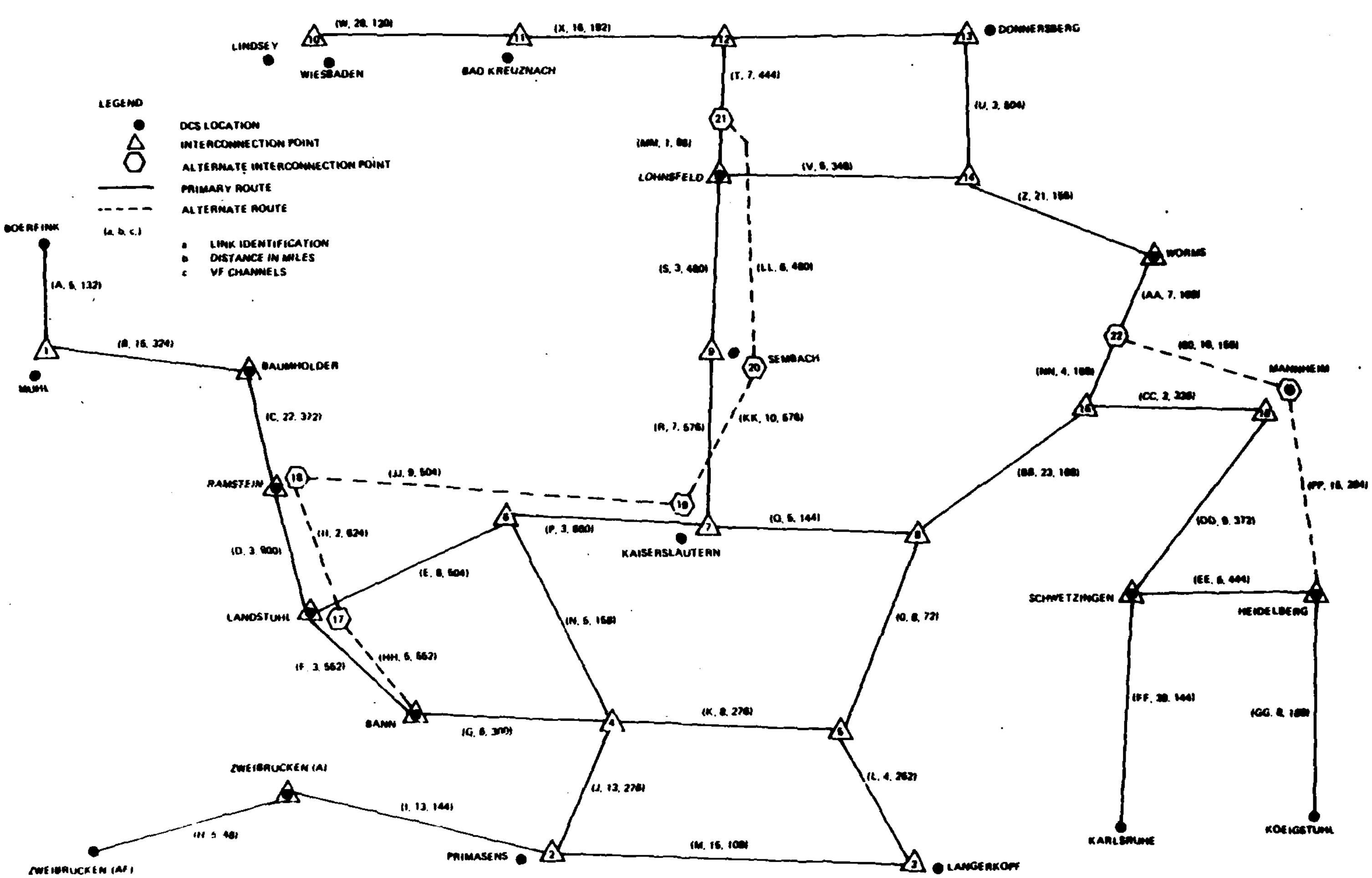


Figure 6.3-1. Primary and Alternate Cable Routes

Table 6.3-5. Summary Costs for German Coaxial Cable System, Primary Network

COST ITEM	1980 TECHNOLOGY 1980 DOLLARS	2000 TECHNOLOGY 1980 DOLLARS	2000 TECHNOLOGY 2000 DOLLARS
Initial Development	0	0	0
Acquisition	57,139	57,139	233,699
Deployment	41,663	41,663	170,402
Total Initial Cost	98,802	98,802	404,101
Operation/Maintenance Cost (p.a.)	345	345	1,411
Spares Consumption (p.a.)	2,870	2,870	11,738
Total Sustaining Cost (p.a.)	3,215	3,215	13,149
Ten-Year Life Cycle Cost	130,952	130,952	525,591

Table 6.3-6. Acquisition Cost for Germany Coaxial Cable System, Primary Network (1980 Dollars)

COST ITEM	YEAR 1980 TECHNOLOGY	YEAR 2000 TECHNOLOGY
Line Terminating Equipment	22,024	22,024
1:5 Protection Switch	5,069	5,069
Repeater & Supervisory Alarms	4,312	4,312
Repeater Housings	2,315	2,315
Coaxial Tubes in PUC Sheath	16,611	16,611
Test Equipment	62	62
Initial Spares	6,744	6,744
Total Acquisition Cost	57,139	57,139

Table 6.3-7. Summary Costs for German Coaxial Cable System, Auxiliary Network

COST ITEM	1980 TECHNOLOGY 1980 DOLLARS	2000 TECHNOLOGY 1980 DOLLARS	2000 TECHNOLOGY 2000 DOLLARS
Initial Development	0	0	0
Acquisition	10,243	10,243	41,894
Deployment	7,590	7,590	31,043
Total Initial Cost	17,833	17,833	72,937
Operations/Maintenance (p.a.)	25	25	102
Spares Consumption (p.a.)	562	562	2,299
Total Sustaining Cost (p.a.)	587	587	2,401
Ten-Year Life Cycle Cost	23,703	23,703	96,947

Table 6.3-8. Acquisition Cost for Germany Coaxial Cable System Auxiliary Network (1980 Dollars)

COST ITEM	YEAR 1980 TECHNOLOGY	YEAR 2000 TECHNOLOGY
Line Terminating Equipment	5,216	5,216
1:5 Protection Switch	108	108
Repeater & Supervisory Alarms	934	934
Repeater Housings	493	493
Coaxial Tubes in PUC Sheath	2,140	2,140
Test Equipment	0	0
Initial Spares	1,350	1,350
Total Acquisition Cost	10,243	10,243

6.3.2.3 System Cost of G-2 System Optical Fiber Option. Technology and cost consideration for optical fiber option of the buried cable system is almost the same as for Hawaii. In Germany, link spans are such that no repeater is required for year 2000 technology.

The system life-cycle costs for both primary network and auxiliary network are shown in Table 6.3-9 and 6.3-11, respectively. The breakdown of acquisition costs for these two networks are displayed in Tables 6.3-10 and 6.3-12.

6.4 ALTERNATIVE TRANSMISSION SYSTEMS FOR TURKEY

Two alternative transmission systems were proposed for Turkey. They are an EHF satellite, designated T-1 and an airborne relay platform, designated T-2, and they have been described briefly in Sections 2 and 4 of this report. The alternative system T-1 is proposed with the assumption that the piggyback transponder or prorated share of large aircraft will be employed and launched.

The alternative system T-2 employs an aircraft which is one of the platforms specified for the study. Turkey is a relatively large country compared to Central Germany. Thus, a high altitude (20 km) aircraft is more desirable than a tethered balloon to increase the line-of-sight distance, which results in decreasing the number of airborne platforms. Considering the size, endurance, and cost, the small aircraft L-450F of E-systems is decided to be the right one. The aircraft is the same one as described in Central Germany.

6.4.1 Alternative Transmission System T-1. The EHF satellite link for Turkey consists of one transponder and 25 small ground terminals which connect all existing DCS sites. The diameter of 2.5M antenna and the output power of 250 watts of transmitter will be used for the ground terminals equipped with TDMA operation.

6.4.1.1 T-1 System Technology and Cost Considerations. The total investment cost of the EHF SATCOM DCS consists of cost of the space segment and the cost of all ground terminals with which it interfaces. The ground terminals are similar in type with those proposed in German airborne relay systems.

Table 6.3-9. Summary Costs for German Optical Fiber System, Primary Network (505 km)

COST ITEM	1980 TECHNOLOGY 1980 DOLLARS	2000 TECHNOLOGY 1980 DOLLARS	2000 TECHNOLOGY 2000 DOLLARS
Initial Development	100	-	-
Acquisition	11,964	4,394	17,971
Deployment	27,775	24,997	102,238
Total Initial Cost	39,839	29,391	120,209
Operations/Maintenance (p.a.)	602	417	1,705
Spares Consumption (p.a.)	591	64	262
Total Sustaining Cost (p.a.)	1,193	481	130,882
Ten-Year Life Cycle Cost	51,769	34,201	139,882

Table 6.3-10. Acquisition Cost for Germany Optical Fiber System, Primary Network (1980 Dollars)

COST ITEM	YEAR 1980 TECHNOLOGY	YEAR 2000 TECHNOLOGY
Cable, Fiber Optics	4,605	1,162
Duct/Aerial Subsystem	2,629	2,629
Electro-Optic TX/RX	3,362	336
Couplers/Connectors	156	78
Initial Spares Complement	775	79
Test Equipment	437	110
Total Acquisition Cost	11,964	4,394

Table 6.3-11. Summary Costs for German Fiber Optic Cable, Auxiliary Network (92 km)

COST ITEM	1980 TECHNOLOGY 1980 DOLLARS	2000 TECHNOLOGY 1980 DOLLARS	2000 TECHNOLOGY 2000 DOLLARS
Initial Development	-	-	-
Acquisition	2,198	753	3,080
Deployment	5,060	4,554	18,626
Total Initial Cost	7,258	5,307	21,706
Operations/Maintenance (p.a.)	110	71	290
Spares Consumption (p.a.)	107	12	49
Total Sustaining Cost (p.a.)	217	83	339
Ten-Year Life Cycle Cost	9,428	6,137	25,100

Table 6.3-12. Acquisition Cost for Germany Optical Fiber System, Auxiliary Network (1980 Dollars)

COST ITEM	YEAR 1980 TECHNOLOGY	YEAR 2000 TECHNOLOGY
Cable, Fiber Optics	794	200
Duct/Aerial Subsystem	460	460
Electro-Optic TX/RX	757	76
Couplers/Connectors	30	15
Initial Spares Complement	157	15
Total Acquisition Cost	2,198	776

The significant difference from Germany is the operating center frequencies. In Turkey, 30/20 GHz frequencies are proposed. No EHF TDMA equipment is available yet, however, many development programs are currently being pursued by companies or institutions sponsored either by government or private enterprise. Therefore, no research and development cost of EHF TDMA is included.

The cost of the space segment may be estimated in three ways:

(a) Assuming the use of the single transponder on the simplest, smallest satellite adequate to meet requirements. The transponder is assumed to have 100 percent redundancy except for the antenna group. A suitable dual spin stabilized aircraft which would supply about 150 watts would have a dry weight of about 500 pounds (without the transponder).

(b) As the prorated share of a larger satellite, assuming that the Turkey transponder is incorporated in the original design, the spacecraft has a total dry weight of 1600 pounds (including 600 pounds of payload). The Turkey transponder is about one-eighth of the power.

(c) The piggyback transponder add-on concept will also be charged with the same proportion of the host vehicle and launch costs as in case (b), but additional costs will be incurred due to necessary changes for extra power and to harness and interface charges.

6.4.1.2 System Cost of T-1 System. For the purpose of cost comparison, three cases of space segment cost will be presented. The transponder cost data is obtained from the TRW AFSAT II SIDS proposal. In the case of (a), the launch costs assume the use of the shuttle ($4,400 per pound) on the standard Air Force procedures, giving a cost of about $13,800 per pound (dryweight). The ground terminal costs are based on a Mitre Corporation study and Page Communication Engineers report. The terminal costs could be reduced by the use of rigidized commercial rather than MILSPEC equipment standards. In the terminal cost, the shelter or van is excluded as in the other country. Tables 6.4-1 and 6.4-2 give the cost of the EHF satellite link system including ground stations. Table 6.4-3 shows the cost of EHF transponder for three cases. It is apparent that cases (b) and (c) are significantly more economical than the use of a small dedicated spacecraft.

Table 6.4-1. Summary Cost for Turkey EHF Satellite Link System

COST ITEM	1980 TECHNOLOGY 1980 DOLLARS (K)	2000 TECHNOLOGY 1980 DOLLARS (K)	2000 TECHNOLOGY 2000 DOLLARS (K)
Initial Development*	1,000	500	2,044
Acquisition	38,968	23,202	94,849
Deployment	5,100	3,060	14,932
Total Initial Cost	45,068	26,762	111,825
Operation/Maintenance Cost)p.a.0	2,500	2,000	9,760
Spares Consumption (p.a.)	450	270	1,318
Total Sustaining Cost (p.a.)	2,950	2,270	11,078
Ten-Year Life Cycle Cost	74,568	49,462	222,605

*EHF TDMA technique is assumed to be transferred from other development programs

Table 6.4-2. Acquisition Cost for Turkey EHF Satellite Link System (1980 Dollars (K))

COST ITEM	YEAR 1980 TECHNOLOGY	YEAR 2000 TECHNOLOGY
(25) TDMA Ground Station	29,623	17,595
Transponder	7,000	4,200
Communication Test Equipment	2,345	1,407
Total Acquisition Cost	38,968	23,202

Table 6.4-3. Cost of Some Transponder Options (1980 Dollars, $ Millions)

OPTIONS	BASIC TRANSPONDER COST	PRORATED SPACECRAFT COST	PRORATED LAUNCH COST	TOTAL COSTS	NOTES
a. Dedicated Small Spacecraft	2.5-5	6	2	10.5-3	Costs for 150 watt transponder, 500 pounds dry weight spacecraft and launch costs
b. Shared Large Spacecraft	2.5-5 (including integration cost)	1.7	0.9	5.4-7.9	Large spacecraft 1600 pounds dry weight, 600 payload, 1200 watt transponder
c. Piggyback Transponder	2.5-5 (including integration cost)	1.7	0.9	6-8.5	150 watt transponder, 70 pounds plus 10 pound harness, with additional integration cost if added after initial host satellite design

6.4.2 Alternative Transmission System T-2. The airborne relay link system for Turkey consists of two relay platforms, 25 small ground terminals, and one ground processor to relay messages to the other relay platform, as shown in Figure 2.3-6. The ground relay terminal is a ground terminal with some processing capability which can receive and transmit to both airborne platforms. Since the same types of aircraft and ground terminals as the Germany G-1 system are proposed for Turkey, the details are not repeated here. One significant difference from Germany is that Turkey has one ground processor and two different sizes of antennas are suggested. Tables 6.4-4 and 6.4-5 show the cost of the aircraft relay-system including ground stations.

Table 6.4-4. Summary Cost for Turkey Airborne Relay System

COST ITEM	1980 TECHNOLOGY 1980 DOLLARS (K)	2000 TECHNOLOGY 1980 DOLLARS (K)	2000 TECHNOLOGY 2000 DOLLARS (K)
Initial Development	1,000	500	2,044
Acquisition	60,629	42,592	207,849
Deployment	14,465	11,571	56,466
Total Initial Cost	76,094	54,663	266,359
Operation/Maintenance Cost (p.a.)	3,498	2,765	13,253
Spares Consumption (p.a.)	803	401	1,956
Total Sustaining Cost (p.a.)	4,301	3,166	15,210
Ten-Year Life Cycle Cost	119,104	86,323	418,459

Table 6.4-5. Acquisition Cost for Turkey Airborne Relay System (1980 Dollars (K))

COST ITEM	YEAR 1980 TECHNOLOGY	YEAR 2000 TECHNOLOGY
(25) TDMA Ground Station	24,686	14,811
(7) Aircraft	15,521	15,521
(7) Relay Communications Equipment	3,654	2,192
Airborne Ground Equipment	10,500	6,300
Communication Test Equipment	3,370	2,030
Initial Spares	2,898	1,738
Total Acquisition Cost	60,629	42,592

(THIS PAGE INTENTIONALLY LEFT BLANK)

7.0 CONCLUSIONS AND RECOMMENDATIONS

This section presents the preliminary conclusions and recommendations resulting from the performance period of the Phase I effort of Evaluation of DCS III Alternatives. Conclusions regarding the proposed transmission alternatives are given in Section 7.1 and recommendations of the transmission media and system designs are in Section 7.2. These conclusions and recommendations may need to be revised, deleted, and/or complemented with new ones during the planned Phase II effort.

7.1 CONCLUSIONS OF SYSTEM ALTERNATIVES

A discussion of an alternative transmission system for each geographical region is given in the following subsections.

7.1.1 Hawaii. The system cost of the proposed alternative transmission system with dollar cost rounded to the nearest million is shown in Table 7.1-1.

Table 7.1-1. Hawaii Transmission Alternative System Cost Summary (1980 Dollars, $Million)

	MILLIMETER WAVE LINE-OF-SIGHT RELAY	BURIED SYSTEM	
		OPTICAL FIBER	COAXIAL CABLE
1980 Technology			
Acquisition	18	5	37
Deployment	3	7	11
Ten-year Sustaining	20	5	24
Life-Cycle Cost	41	17	72
2000 Technology			
Acquisition	5	1	37
Deployment	2	7	11
Ten-year Sustaining	6	2	24
Life-Cycle Cost	13	10	72

The relatively high cost of the millimeter wave line-of-sight system for 1980 reflects the fact that the current state-of-the-art is not quite ready for mass applications. The estimates for the "1980 Technology" version of this candidate are based on manufacturers' willingness to contract in 1980 for equipment fitting the requirements, but which might actually be available for installation in 1983. Note that the 2000 Technology reduces the life-cycle cost by a factor of 3. Although the life-cycle cost of the millimeter wave line-of-sight transmission system is slightly higher than that of the buried cable system using optical fiber, the millimeter wave system is a strong contender. This is because the acquisition of land and right-of-way are not included. These costs certainly would be higher for a buried cable system and could result in a cost advantage for millimeter wave LOS system.

The primary drawback of the buried cable system is that significant time is necessary for installation--to determine routing as well as actual installation. This consideration is reflected in the acquisition and deployment costs, the latter dominating the cost of the fiber optic cable system using year 2000 technology and component costs.

The coaxial cable system, however, is quite expensive--a reflection of the required use of digital transmission and coaxial cable. Inexpensive equipments intended for digital transmission over coaxial are not presently available, nor are they expected to be in the future because of the superior characteristics of fiber optic systems. The current cost of coaxial cable itself is high, and there is no reason to believe that future costs will be lower.

It should also be noted that a significant number of the Oahu cable routes are relatively lightly loaded in quantity of equivalent voice channels. In these cases, T1 wire-pair cables could carry the required traffic at a lower cost than the coaxial cable specified for this task. If wire-pair cable were substituted where possible for coaxial cable, a significantly lower cost would result; however, cost would remain higher than the fiber optic system.

7.1.2 Germany. Table 7.1-2 tabulates system cost of the proposed airborne relay systems and buried cable systems for the central region of West Germany. The costs are rounded to the nearest million.

Table 7.1-2. German Transmission Alternative System Cost Summary (1980 Dollars, $Million)

	AIRBORNE RELAY SYSTEM		BURIED CABLE SYSTEM	
	TETHERED BALLOON	AIRCRAFT	OPTICAL FIBER	COAXIAL CABLE
1980 Technology				
Acquisition	42	43	12	57
Deployment	13	8	28	42
Ten-year Sustaining	30	37	12	32
Life-Cycle Cost	85	88	52	131
2000 Technology				
Acquisition	31	30	4	57
Deployment	12	7	25	42
Ten-year Sustaining	24	28	5	32
Life-Cycle Cost	67	65	34	131

Considered either in terms of initial cost or life-cycle cost, the fiber optical system is clearly the best choice. The respective arguments for optical fiber and coaxial cable for Hawaii apply as well to the German alternatives.

The airborne relay system employing either tethered balloon or aircraft has the advantage of circumventing the cable route and installation problem. However, the airborne relay is considered to be significantly more vulnerable as a communications system than the buried cable system.

Loss of the on-air balloon aircraft would result in the complete loss of the entire network until the backup balloon aircraft were in place. As previously indicated, the airborne relay system is also subject to jamming and EMP effect.

In addition, the deployment of either a tethered balloon or on-orbit aircraft is subject to the approval of the civil aviation authority.

7.1.3 Turkey. In view of the large area to be covered in Turkey, a satellite system operating at 20/30 GHz and an airborne relay system consisting of two platforms are proposed. The system cost rounded to the nearest million of these two alternatives are shown in Table 7.1-3. It is apparent that the EHF satellite system is a cost-effective candidate.

In the Phase IA Report, the EHF satellite system proposed consists of only nine earth stations at Izmir, Balikesir, Sohin Tepesi, Ankara, Elmajaz, Sinop, Erhac, Diyarbuakie, and Incirlik. However, the proposed system provides EHF ground terminals for each node in Turkey, and all outdated tropospheric systems are eliminated.

Note that the EHF system cost is compatible with that of the fiber system of Germany which comprises an almost equal number of nodes, but distributed in a much smaller area. If an optical fiber system was proposed for Turkey, the cost would be higher due to the vast distance between most stations.

Table 7.1-3. Turkey Transmission Alternative System Cost Summary (1980 Dollars, $Million)

	EHF SATELLITE SYSTEM	AIRBORNE RELAY SYSTEM (AIRCRAFT)
1980 Technology		
Acquisition	40	62
Deployment	5	14
Ten-year Sustaining	30	43
Life-Cycle Cost	75	119
2000 Technology		
Acquisition	23	43
Deployment	3	12
Ten-year Sustaining	23	30
Life-Cycle Cost	49	85

7.2 RECOMMENDATIONS

Recommendations on research and development programs regarding transmission media and system designs are presented in this subsection. These recommendations are identified during the performance period of Phase IA and Phase IB efforts. Scope of recommendations is certainly limited by these three geographic areas investigated and does not necessarily cover the whole spectrum of DCS. These recommended research and development programs need further definition and substantiation which would better await the end of the Phase II effort of this program.

7.2.1 Atmospheric Effects on Millimeter Wave Propagation. As previously indicated, the design of either a millimeter wave LOS system or EHF satellite system can be done deterministically except for the atmospheric effects, particularly the rain attenuation which has to be treated probabilistically. Statistical information of rain parameters such as rain cell size, rain rate, duration, temporal and spatial distribution, etc., are need for a more accurate link performance analysis. Additionally, attenuation, depolarization, scattering, and amplitude and phase variation of an electromagnetic signal propagation through an inhomogeneous rainfall area in terms of rain parameters mentioned above are also needed for system performance analysis.

A research program of atmospheric effects on millimeter wave propagation is consequently recommended. This program should consist of the following efforts:

- Collection of statistical data of rain parameters on a global basis or at least for the geographic areas of interest
- Conduct theoretic analysis or computer simulation of effects of rain on electromagnetic wave propagation
- Experimentally observe various kinds of effects of rain for terrestrial and satellite paths
- Correlate theoretic results and experimental observations and validate theoretic analysis and simulation models
- Experimentally and theoretically investigate various diversity techniques; space, frequency, polarization diversity, etc., for the purpose of overcoming the short term fading effect or rain attenuation

- Analyze the scintillation phenomenon of signal through the fluctuating atmosphere.

7.2.2 Millimeter Wave LOS Communications System. There are currently very heavy research and development activities on millimeter waves, sponsored either by government agencies or by private enterprise; however, emphasis is placed on components or devices. There is no millimeter wave communication system available because of the absence of a market. It was found during the cost estimate for the proposed millimeter wave system in Hawaii that production digital radio is simply not available and no such radio is under development.

Consequently, it is recommended that a development effort be initiated and sponsored by a government agency. The prototype sets should be made available for millimeter wave propagation test as mentioned in "Atmospheric Effects on Millimeter Wave Propagation."

It should be pointed out that the millimeter wave LOS radio is not merely a microwave LOS radio scaled upward in frequency. Some millimeter wave unique system issues and design features should be dealt with in this program. An example is the adaptive carrier level control. Since the millimeter wave is subject to heavy rain attenuation, the transmitter should have large enough power output for compensation; say, for rain occurrence at 5 or 1 percent of the time. This power level then is probably many dB higher than what is needed for fine weather. This excessive power may cause interface problems or drain power supply. Therefore, an adaptive carrier power level control between adjacent repeater stations is needed, and research and development effort for the said control should be part of this program.

7.2.3 Packet Radio Applications. The satellite operating frequency will gradually and continuously move upward. The higher frequencies enable the use of multiple-beam spot-antenna on board the satellite for transmitting and receiving. Coverage area of 100 miles not necessarily circular in shape is feasible. The multiple spot beams coupled with packet radio technique will provide communications services which would not be possible by using conventional technology.

The first part of this research project investigates the use of a satellite as a packet radio control station interconnecting many ground terminals either in a small area or distributed over the globe. Each terminal may communicate with other terminals in data or digitized voice. Multiple spot beams will be considered for the frequency re-use and anti-jamming purpose. Comparison of the proposed packet satellite with other forms utilizing the same satellite capacity should be conducted.

The second part of this project is to examine the utility of packet technology to a terrestrial radio network; for example, the proposed Hawaii millimeter wave system. This is in contrast with the current packet radio fast bed which emphasizes tactical applications not for day-to-day long haul communications needs.

7.2.4 Airborne Relay Platform and Related Technology. Two different kinds or airborne relay platforms are proposed for DCS III transmission alternatives; these are tethered balloon and manned aircraft. The tethered balloon is too bulky and makes a good target for sabotage. In addition, apparently the altitude of 15,000 feet is the possible maximum. The proposed manned aircraft is of the right size for this mission, however, aircraft endurance, flying crew fatigue, logistic support and cost are difficulties encountered for the operation of an aircraft relay system.

Since the research and development of an airborne platform has been sponsored by other military services or agencies, it will not be recommended here; however, closely monitoring the status and progress of such programs is suggested. Programs of particular interest are the high altitude powered platform and solar powered platform.

The high altitude powered platform has been described in Section A.16 of Appendix A, Transmission Media of Final Phase IA Report. The platform can stay in-air for one year with power supplied by microwave beam from the ground.

The other developing platform of interst is the Navy solar powered platform which can stay on-air for long times.

The development of platforms mentioned above and other platforms, if any should be monitored, and application of these platforms for relaying should be examined. Operational characteristics of a platform impact communications relay equipment, particularly the antenna size, physical form, and radiation pattern. Research and development for antennas may be needed.

7.2.5 Platform Antenna Array and Adaptive Control Electronics Development. Two kinds of antennas are required for the airborne relay platform. The first one is the transmitting and receiving antennas for the area covered by the platform. In general, for the relatively low altitude of interest, it is an antenna with hemispheric coverage. The second is the antenna used for inter-platform link. Because of either the movement of a tethered balloon or an orbiting aircraft, an antenna with doughnut shape radiation pattern is assumed for the alternative system in Turkey. The gain of these two types of antennas is quite low. In addition, because of the wide beamwidth, these two types of antenna are vulnerable to jamming.

In view of the low power level involved, higher frequency used, and the recent development of large-scale integration techniques, it is feasible now to develop a real-time adaptive antenna array which can radiate one or more pencil beams in response to each of the incident waves. This array will operate on the principle of retrodirective array. This array has many interesting applications; one of them, related to the present task, is that it can be used as an antenna for a terminal or a repeater station of a packet radio network. A station of such network may have a few stations of the same network within line-of-sight range; new links between these stations may be set up due to routing of packets.

7.2.6 Submarine Cable Employing Optical Fibers. A submarine cable system is a competitor of a satellite for transoceanic communications traffic. The current submarine cable carries 5000 or more high quality voice channels which is the total throughput of an INTELSAT Satellite IV. A satellite system is operated on multiple access basis; however, a submarine cable only connects two points or a series of points along a cable route.

If the coaxial tube of the current submarine cable is replaced by a number of optical fibers but keeps the cable size unchanged, the capacity of such cable would be increased by a few orders of magnitude. However, there are a few design problems which await solution.

- Optical fiber suitable for submarine cable use, particularly the mechanical property of the fiber
- Power supply for the regenerative repeaters of optical fibers
- Tradeoff among the number of optical fibers, the capacity of each fiber, and regenerative repeaters
- Cable system designs such as cable transmission objectives, system capacity, repeater spacing, repeater design, etc.

A fiber optic submarine cable is very attractive in cost in the DCS III time frame and is a useful complement to the satellite system which is subject to anti-satellite threat, jamming, and nuclear blackout attack.

Furthermore, the recently and rapidly advanced integrated optics and optical switching technologies will lead to a communications network of star, mesh, or hybrid form with optical submarine cables as links of the network. It is feasible to have one such network for each of the water masses of the world; for example, a Pacific network interconnecting all seaports or major strategic points around the Pacific Ocean.

Investigation, research, and development work for optical submarine cable, integrated optics and switching devices for undersea use, and system design have not been undertaken yet; therefore, it is recommended that such an endeavor should be initiated.

(THIS PAGE INTENTIONALLY LEFT BLANK)

REFERENCES

1.1-1 TRW, "Evaluation of DCS III Transmission Alternatives, Phase IA Final Report," May 1980, TRW Doc. No. 35142

TRW, "Evaluation of DCS III Transmission Alternatives, Appendix A, Transmission Media," May 1980, TRW Doc. No. 35142

TRW, "Evaluation of DCS III Transmission Alternatives, Appendix B, Regulatory Barriers," May 1980, TRW Doc. No. 35142

TRW, "Evaluation of DCS III Transmission Alternatives, Appendix C, Regional Consideration and Characterization," May 1980, TRW Doc. No. 35142

2.1-1 ITU, "Final Acts of the World Administrative Radio Conference," Geneva, 1979 (Draft Document supplied by State Department)

2.1-2 CCIR, "XIIth Plenary Assembly," Kyoto, 1978

2.1-3 CCITT, "Sixth Plenary Assembly," Geneva, 1976

3.2-1 Kirk, K. W. and J. L. Osterholz, "DCS Digital Transmission System Performance," DCEC Technical Report No. 12-76, November 1976

3.2-2 Spilken, J., Digital Communications by Satellite, Prentice-Hall, N. J., 1977

3.2-3 Nielson, P., J. Osterholz, E. Pusone, and I. Vogt, "Digital Troposcatter Test Program Over Two Ace High Links," DCEC Technical Report 12-78

4.1-1 Bell Telephone Laboratories, "Transmission Systems for Communications." Revised Fourth Edition, 1969, pp. 626-635

4.1-2 D. Cowan, "The LD-4 System." Conference Record, International Communication Conference, 1977

4.2-1 A Vigants, "Space Diversity Engineering," BSTJ, Vol. 54, No. 1, pp. 103-142, January 1975

4.2-2 A. Vigants, "Number and Duration of Fades at 4 and 6 GHz," BSTJ, Vol. 50, No. 3, pp. 815-841, March 1971

4.3-1 P. L. Rice, et al, "Transmission Loss Predictions for Tropospheric Communication Circuits," NBS Technical Note No. 101, January 1967

4.3-2 M. Schwartz, et al, "Communication Systems and Techniques," McGraw-Hill, N.Y., 1966

4.3-3 J. Osterholz and D. Smith, "The Effects of Digital Tropo Error Statistics on Asynchronous Digital System Design," 1975 National Telecommunications Conference Proceedings, Vol. II, pp. 28-25ff.

4.3-4 J. Osterholz, "Design Considerations for Digital Troposcatter Communications," AGARD Conference Proceedings, No. 244, pp. 22, 1978

4.3-5 S. Rice, "Statistical Properties of a Sine Wave Plus Random Noise," BSTJ, Vol. 27, January 1948

4.3-6 J. Grosskopf and L. Fehlhaben, "Rate and Duration of Signal Deep Fades in Troposcatter Links," NTZ-CJ, No. 3, 1962

4.3-7 D. Kennedy, "Digital Error Statistics for a Fading Channel," Conference Record, International Conference on Communications, Vol. I, June 1973

4.3-8 A. Barsis, et al, "Performance Predictions for Single Tropospheric Communication Links for Several Links in Tandem," NBS Technical Note 102, August 1961

4.4-1 J. W. Ryde and D. Ryde, "Attenuation of Centimeter and Millimeter Waves by Rain, Hail, Fogs and Clouds," Res. Labs of the General Electric Company, Wembley, England. Rep. 86% (1945)

4.4-2 D. C. Hogg and T. S. Chu, "The Role of Rain in Satellite Communications," Proc. IEEE, 63, September 1975

4.4-3 D. C. Cox, "Design of the Bell Laboratories 19 and 28 GHz Satellite Beacon Propagation Experiment," IEEE International Conference on Communication Record, June 17-19, 1974, Minneapolis, Minnesota, pp. 27 E1-27 E5

4.4-4 J. O. Laws and D. A. Parsons, "The Relation of Raindrop Size to Intensity," Trans. Amer. Geophysical Union, Vol. 24, pp. 432-460, 1943

4.4-5 R. W. Crane, "A Global Model for Rain Attenuation Prediction," EASCON '78 Record, IEEE Publication 78 CH, 1354-4AES

4.4-6 L. G. Mundie and N. E. Feldman, "The Feasibility of Employing Frequencies between 20 and 300 GHz for Earth-Satellite Communication Links," Project Report R-2275 DCA, Rand Corp. (May 1978)

5.1-1 Bell Telephone Laboratories, Transmission System for Communications, Revised Fourth Edition, 1969, pp. 626-635

REFERENCES (Continued)

5.1-2 Tadashi Amemiya, Makoto Niiro and Tetsuo Ogawa, "A 34 Mb/s Digital Repeated Line System," ICC 1978

5.1-3 D. Cowan, "The LD-4 System," ICC 1977

6.2-1 DCA, "Circuit and Trunk File Data Elements and Codes Manual of the Defense Communications System (DCS)," DCA Circular 310-65-1, May 1979

(THIS PAGE INTENTIONALLY LEFT BLANK)


FILME
8